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ELECTROMAGNETIC CHAMBER MODIFICATIONS AND MEASUREMENTS.(U)
MAR 77 D I HARPRING, R L JUDE, J M ROE N60921-76-C-A273
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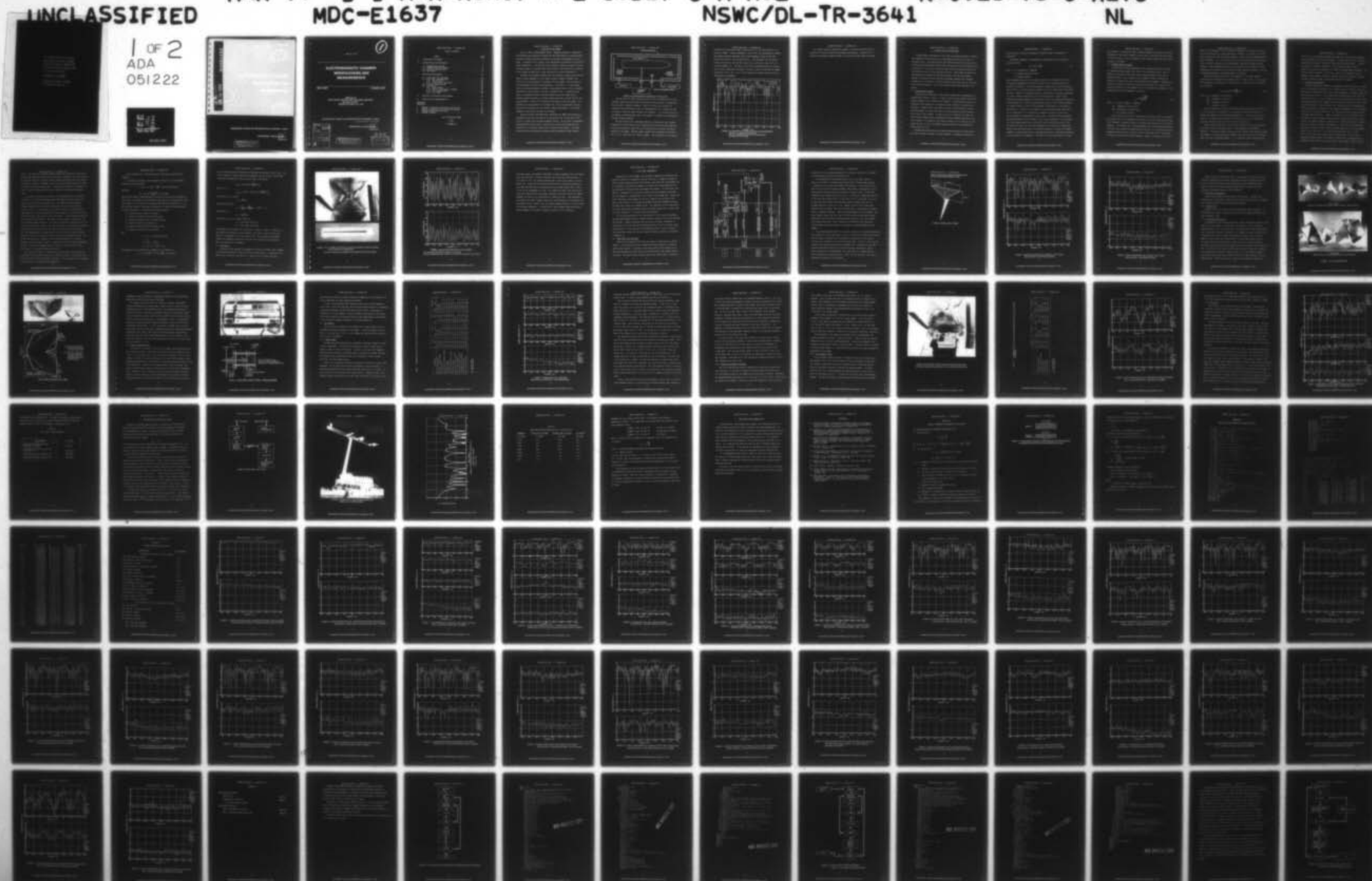

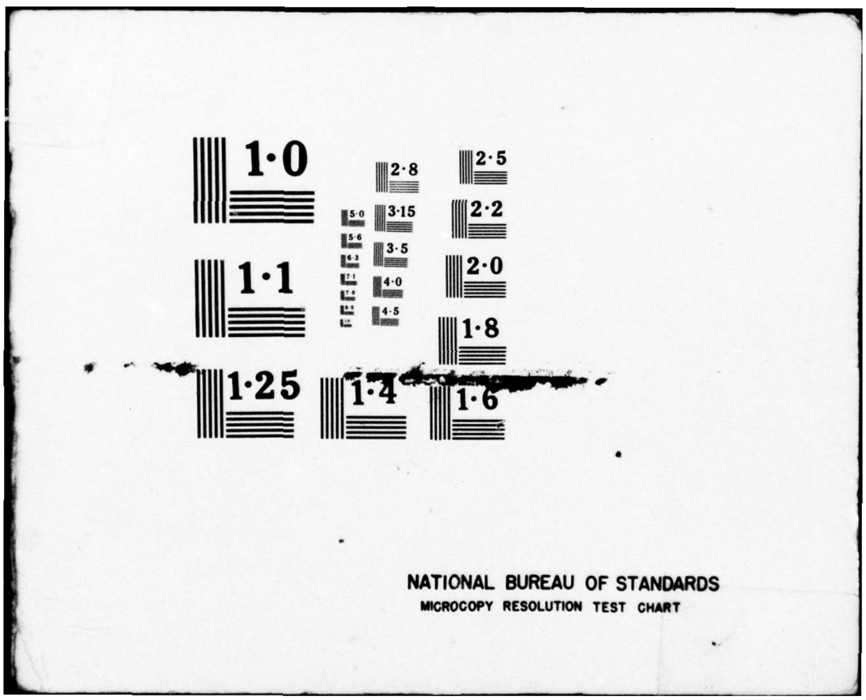
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COPY NO. 27

ELECTROMAGNETIC CHAMBER MODIFICATIONS AND MEASUREMENTS

MDC E1637 **31 MARCH 1977**

SUBMITTED TO:
NAVAL SURFACE WEAPONS CENTER-DAHLGREN LABORATORY
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1. INTRODUCTION AND SUMMARY

The U. S. Naval Surface Weapons Center - Dahlgren Laboratory is developing the technology base required to enhance the cost-effectiveness of preventing Navy electronic systems from being vulnerable to high power electromagnetic environments. One aspect of this program is the improvement and extension of MIL-STD-1377 (Navy) (Reference 1). MIL-STD-1377 (Navy) presents a method for measuring shielding effectiveness of aerospace cables and enclosures, and the possible extensions of the concept include active system susceptibility testing (Reference 2).

The basic high frequency (greater than one gigahertz) concept of MIL-STD-1377 (Navy) involves placement of a test sample inside a conductive chamber, the injection of an electromagnetic environment into the chamber, and the tuning of this environment by various tuning mechanisms. See Figure 1. In the original version, the tuning mechanism included a crossed dipole field stirrer, and double stub tuners (or equivalent) on the input and output lines. In operation, the tuners are adjusted to obtain a maximum reading on the test sample and the reference antenna (probably at different tuning positions), and the ratio of the received power is taken as the shielding effectiveness of the test sample. The technique has good repeatability (although this varies with operators) and has been shown to correlate well with anechoic chamber measurements. Its greatest drawback is the relative slowness of the method.

During a previous contracted effort (Reference 3), MDAC-E had shown that an improved field stirrer could replace the crossed dipoles, and that use of this stirrer in rotation only produced acceptable results. The increase in measurement speed permitted far more cases of interest to be studied than before and the derivation of a statistical definition of shielding effectiveness. The human factors were also eliminated and computer-aided measurements became feasible.

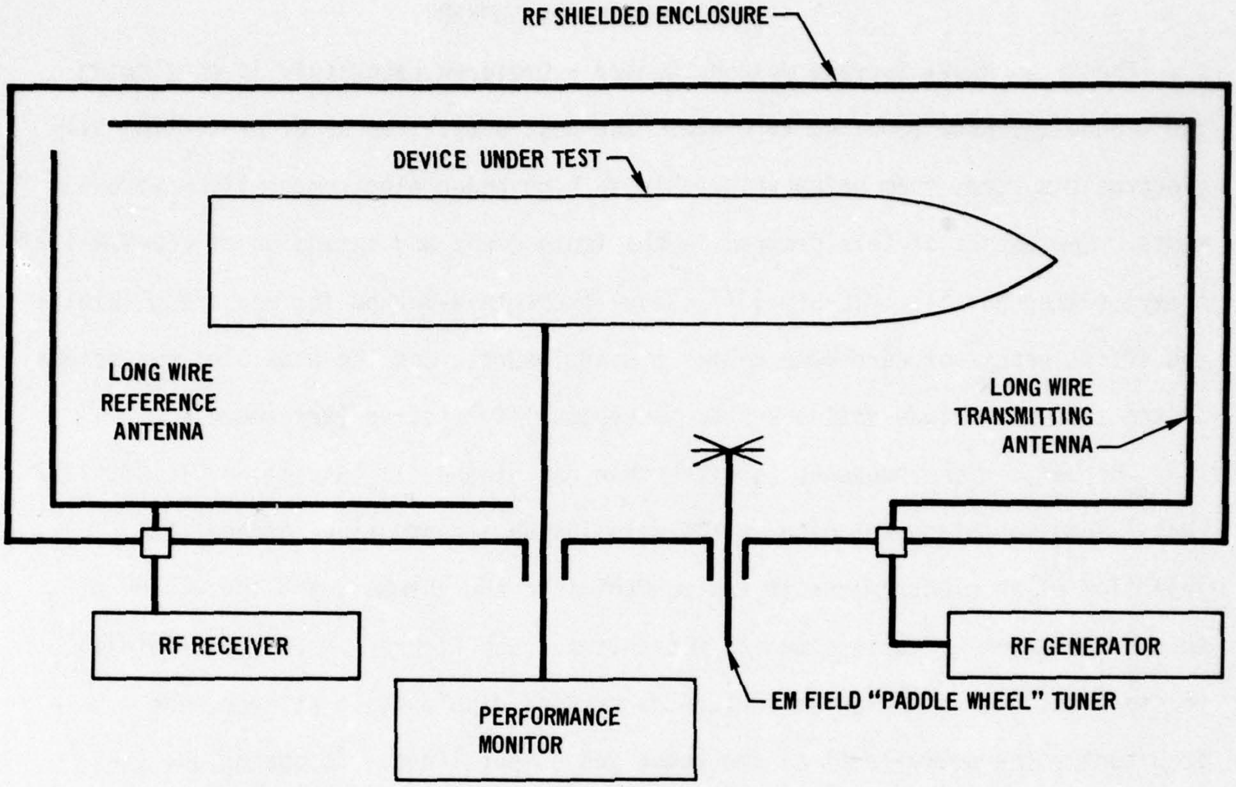


FIGURE 1 ELECTROMAGNETIC SUSCEPTIBILITY TEST SETUP

The new tuner left much to be desired at the lower frequencies (one to two gigahertz) where there were rather large peak-to-peak excursions in transmission loss over small frequency increments. There is no clear cut criterion for evaluating the effectiveness of the stirring mechanism, but it "should" be able to produce a relatively smooth response with frequency. It is possible that the uncertainty of any measurement made in the chamber is related to the magnitude of the peak-to-peak variations.

The main thrust of this contracted effort was to design and test improved antennas and field stirrers, and to investigate the free-field pickup properties of typical twisted pair cables for use in establishing an absolute calibration method for the chamber. Matched longwire antennas were designed and validated for a 3 x 3 x 5 foot (91 x 91 x 152 cm) chamber. Design equations and validation

procedures are described to permit installation of the improved antennas in an arbitrary chamber. Several paddlewheel field stirrers and implementation schemes were studied, and the individual results were compared in terms of mean and standard deviation for the transmission loss. The paddlewheel stirrer design process was empirical, but the best tuners can be scaled up or down to fit an arbitrary chamber size. The impact of the work accomplished during this contract can be briefly summarized by reference to Figure 2, which illustrates the chamber transmission loss in the 1.0 to 1.2 GHz frequency band before and after the test configuration improvements.

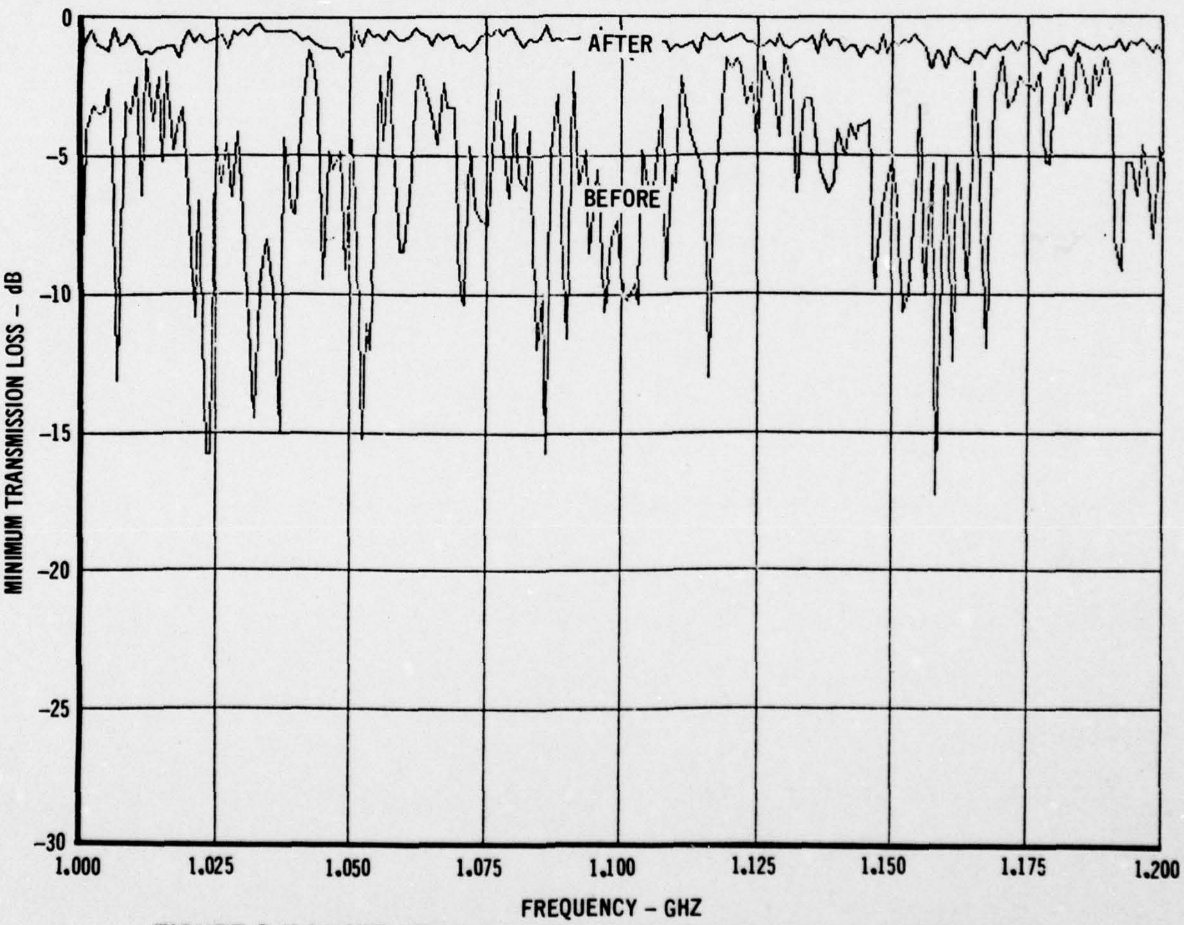


FIGURE 2 ILLUSTRATION OF TUNING CONFIGURATION IMPROVEMENTS
(BOTTOM LINE - ORIGINAL CONFIGURATION)
(TOP LINE - COMBINED EFFECT OF TUNING IMPROVEMENTS INCLUDING TWO FIELD TUNERS)

This report contains representative samples of the data obtained which are required to illustrate significant performance improvements. Complete sets of the data are available at MDAC and NSWC in the form of the data tapes and graphs.

2. ANTENNA DESIGN AND DEVELOPMENT

The performance requirements for the input and reference antennas in the EM test chamber are the same as for any input/output coupling loop or probe in a microwave cavity. The coupling device must couple RF energy from a coaxial link into the cavity and establish the EM field with minimum loss and reflections back to the source. In the case of the multi-mode cavity, the long wire antenna has been found to be an efficient coupling device for a large number of modes which are desirable for changing the coupling parameters into the test specimen. However, to maintain efficient coupling and matched impedance over broadband frequencies, it is necessary to maintain careful control over physical dimensions of the long wire antenna. This is verified by the test data contained in this report.

2.1 Antenna Design Concept

Previous work in MIL-STD-1377 type EM test chambers has not addressed the antenna design problem in detail. Instead, a manual tuning procedure matched the antenna impedance at the selected test frequency. Consideration was given to an automated tuning method where a computer would do essentially the same tuning procedure. Trombone tuning stubs would be driven by stepping motors, and the resulting changes in tuning state would be sensed through directional couplers and fed back to the computer. Through a series of iterations, the shunt and series tuning elements would be adjusted for optimum impedance matching at each test frequency. The complexity and inherent slowness of this concept led us to reject the idea in favor of broadband impedance matching using exponentially tapered matching lines.

Broadband antenna matching using tapered matching sections at each end of the antenna reduces the number of design problems. The antenna and matching

section designs are based on background information found in references (4) through (9).

The antenna impedance is approximated by the equation for an unbalanced transmission line:

$$Z_c = 138 \log \frac{4h}{d} \tag{1}$$

where: Z_c = characteristic impedance

h = antenna spacing from wall

d = antenna diameter

Actual impedance looking into the antenna installed in the chamber varies from this equation depending on the mode of coupling to the reference antenna and frequency of operation. The coupling modes are changed by the stirring mechanism; hence, there is a different antenna impedance for each of the possible field tuner positions. However, the impedance values of significance are the ones corresponding to the "minimum transmission loss" field tuner position. Manual tests indicate the antenna impedance is approximately that of the unbalanced transmission line when modes are stirred to produce maximum coupling to the reference antenna. The antenna concept is similar to the Beverage or Wave Antenna, as described in reference (8). To maintain a low VSWR over a broad frequency band, the antenna must be terminated in its characteristic impedance and must be driven from a source impedance of approximately the same value. The major difference between the Beverage antenna and this concept is that a wave propagated in one hemisphere from the Beverage antenna has no reflections; waves leaving the antenna in the EM chamber are subject to reflection regardless of the direction of propagation. However, when maximum coupling to the reference antenna is achieved, the antenna impedance is approximately that of a Beverage antenna and is approximately defined by the transmission line equation. The effect of the matched antenna in the EM

test chamber is to reduce the range of antenna impedance variations such that the impedance at a particular frequency is more likely to be within the tuning range of the field tuner. Thus, the probability that minimum transmission loss will be attained is increased.

2.2 Impedance Matching Concept

A transmission line whose impedance varies exponentially along its length has impedance matching capabilities similar to an exponential horn. Also, it behaves as a high-pass filter whose cutoff frequency depends on the rate of exponential taper. Such a tapered line has apparent utility in matching an antenna to a transmission line of lower characteristic impedance. References (2) through (7) include a collection of formulas which express the relation of the electrical properties of the exponential line to the mechanical dimensions. From reference (5) the cutoff frequency is given by:

$$f_c = \frac{55 \log \left(\frac{Z_{0L}}{Z_{00}}\right)}{\ell} \qquad (2)$$

where: f_c = cutoff frequency in megahertz

Z_{0L} = impedance of the load end

Z_{00} = impedance of the source end

ℓ = line length in meters

If the load end of the line is terminated in a load Z_{0L}, then for frequencies much greater than fc, the impedance at the input of the line is approximately Z_{00}. As the frequency is decreased toward f_c, increasing deviations occur in the input impedance. Per reference (4), if the exponential line is placed between constant-K low pass filter sections and M-derived half sections, it is possible to keep the impedance deviations within 5 percent of the required value for all frequencies 15 percent or more above the cutoff frequency. Where it is desired to limit the

length of the exponential line, or where exact matching is required, such terminating filter sections have useful applications. However, it is simpler to increase the line length such that the working frequency is always very high compared to the cutoff frequency. If it is not desired to use filter sections at the line terminations, the cutoff frequency must be considerably lower than the lowest working frequency. Where impedance deviations of 10 percent can be tolerated, the cutoff frequency must be approximately one tenth the lowest operating frequency. This was the approach adopted for the tapered matching line design.

The design frequency band of the test chamber was 1 to 10 GHz, thereby indicating cutoff frequency for the tapered line of .1 GHz or less. The characteristic impedance of the tapered line at any point (x) along the line can be defined by the equation:

$$Z_{(x)} = Z_{00} \exp \{(\ln \frac{Z_{0L}}{Z_{00}})\, x/\ell\} \qquad (3)$$

where: $Z_{(x)}$ = *impedance at position (x)*

Z_{00} = impedance at source end

Z_{0L} = impedance at load end

ℓ = length of the line

With the required line length and impedance defined by equations (2) and (3), it is only necessary to determine the cross-sectional dimensions necessary to provide the impedance values indicated by equation (2). From the various transmission line configurations possible, the microstrip line with a single ground plane was selected as the most practical for our application.

Wheeler's work (reference 7) on microstrip lines gives a wide strip approximation and a narrow strip approximation. These equations are presented in Appendix A. Preliminary designs indicated that the tapered lines required to match the antennas in the EM chamber would encompass both the narrow strip line and the wide strip line as defined by Wheeler. It is essential to avoid discontinuities

in the line, so interpolation between the narrow strip and wide strip approximations was necessary in the overlap program. A program was written for a Hewlett Packard desk calculator to perform the microstrip width calculations. A copy of the program is included in Appendix B. The calculator printout, also in Appendix B, provides the necessary line widths at selected length increments. The resulting cutoff frequency is also given. Inputs to the program are source impedance, load impedance, dielectric constant, dielectric thickness, conductor thickness, conductor length, and selected calculation increments.

2.3 Practical Considerations

Although the equations presented can adequately define the electrical requirements of the antenna and matching lines, certain physical limitations necessitate some practical design selections. Basic antenna dimensions - diameter, length, and spacing away from the wall - were selected for good performance, consistant with physical constraints. The wire diameter must be large enough to be rigid and have a reasonable characteristic impedance and low dissipation losses, yet small enough to enable attachment to the microstrip line. Spacing away from the chamber wall affects characteristic impedance of the antenna, wave impedance of the surrounding field (E/H), and coupling efficiency. The antenna should be as long as possible to produce maximum radiation. However, the physical size of the chamber limits the length if excessive antenna overlap and wave interference effects are to be limited. The antenna dimensions selected for our antenna were based on a compromise of the factors mentioned. The antenna is a .125 inch (3.175 mm) diameter aluminum wire spaced 3 inches (7.62 cm) from the chamber wall and is zig-zagged across a 3 x 5 foot (0.91 x 1.52 m) wall and extends onto two 3 x 3 foot (0.91 x 0.91 m) walls for a total length of approximately 11 feet (3.35 m). Aluminum was chosen because its electrical properties are less susceptible to formation of metal oxides on the wire surface, unlike copper or brass and their

oxides. (The difficult soldering problem inherent with aluminum has been solved by using high temperature solder and a special flux intended for use with aluminum. The flux and solder are available at Sears, Roebuck and Company under that store's brand name.) The wire is embedded in the low loss polystyrene-based plastic foam to maintain the spacing from the wall. The dielectric constant of the material is 1.02 $\pm$ .01 with a dissipation factor below .0002 over the operating frequency range.

The length of the microstrip taper was also determined partly by practical limitations. The transition between antenna and tapered line must be physically smooth to avoid electrical discontinuities. The antenna spacing previously selected indicates that the microstrip dielectric thickness should be about 3 inches (7.62 cm). This thickness is not feasible because of the excessively wide microstrip line and discontinuity which would appear in the coaxial to microstrip transition at the source end of the microstrip. A more reasonable selection for the microstrip thickness is .125 inches (3.175 mm) which is available in low loss dielectric-copper laminates. This leaves the problem of transition from .125 inch (3.175 mm) spacing to the 3 inch (7.62 cm) spacing. The problem was solved by dividing the electrical taper into two tapers which are physically different. The first tapered section is made from the .125 inch (3.175 mm) copper laminate. The width of the line is tapered to provide the required impedance matching. The second tapered section is composed of the aluminum antenna wire of constant diameter, but the spacing to the wall is tapered to provide the required impedance matching. The rate of impedance taper is the same for both sections so that electrically it is one continuously tapered line.

The length of the taper is fixed by physical constraints, and the point of transition from the microstrip taper to air dielectric taper is fixed by the wire diameter and the microstrip dielectric thickness. The air dielectric line impedance at the transition is calculated from equation (1).

If the aluminum wire is attached directly to the top of the microstrip conductor:

h = dielectric thickness + twice conductor thickness + 1/2 wire diameter.

Substituting selected values

$$h = .125 + 2 \times .0014 + \frac{.125}{2} = .1903 \text{ inch } (4.831 \text{ mm})$$

therefore

$$Z_c = 138 \log \frac{4 \times .1903}{.125} = 108.27 \text{ ohms}$$

The microstrip taper is then designed to transform the 50 ohm input impedance to 108.27 ohms. The lengths of each tapered section must be a calculated part of the total length so as to maintain the impedance taper defined by equation (3). The total physical length of the taper was selected as 19 inches (48.26 cm) because of chamber dimensions. If we define the following symbols:

ℓ_T = total electrical length of the taper

ℓ_1 = electrical length of the microstrip taper

ℓ_2 = electrical length of the air dielectric taper

L_1 = physical length of the microstrip

L_2 = physical length of the air dielectric taper

k = dielectric constant of the microstrip

then:

$$L_1 + L_2 = 19 \text{ inches } (48.26 \text{ cm})$$

$$\ell_2 = L_2$$

$$\ell_1 = \sqrt{k}\, L_1 = \sqrt{2.5}\, L_1$$

$$\ell_T = \ell_1 + \ell_2 = \sqrt{2.5}\, L_1 + L_2$$

From equation (1) the characteristic impedance of the antenna is:

$$Z_c = 138 \log \frac{4h}{d} = 138 \log \frac{4 \times 3}{.125} = 273.55 \text{ ohms}$$

Thus the microstrip taper transforms the impedance from 50 ohms to 108.27 ohms, and the air dielectric taper transforms the impedance from 108.27 ohms to 273.55 ohms. To maintain the same taper rate, the total taper is defined by:

$$Z_{(x)} = 50 \exp\{(\ln \frac{273.55}{50}) x/\ell_T\}$$

and at $x = \ell_1$

$$Z_{(\ell_1)} = 108.27 = 50 \exp \{(\ln \frac{273.55}{50}) \frac{\ell_1}{\ell_T}\}$$

Solving this for ℓ_1 yields

$$\ell_1 = .45462\ \ell_T$$

Substituting into (4)

$$\ell_T = \frac{\ell_1}{.45462} = \frac{\sqrt{2.5}}{.45462} L_1 = \sqrt{2.5}\ L_1 + L_2$$

Solving for L_2:

$$L_2 = 1.896769\ L_1$$

Then, since $L_1 + L_2 = 19$ inches (48.26 cm)

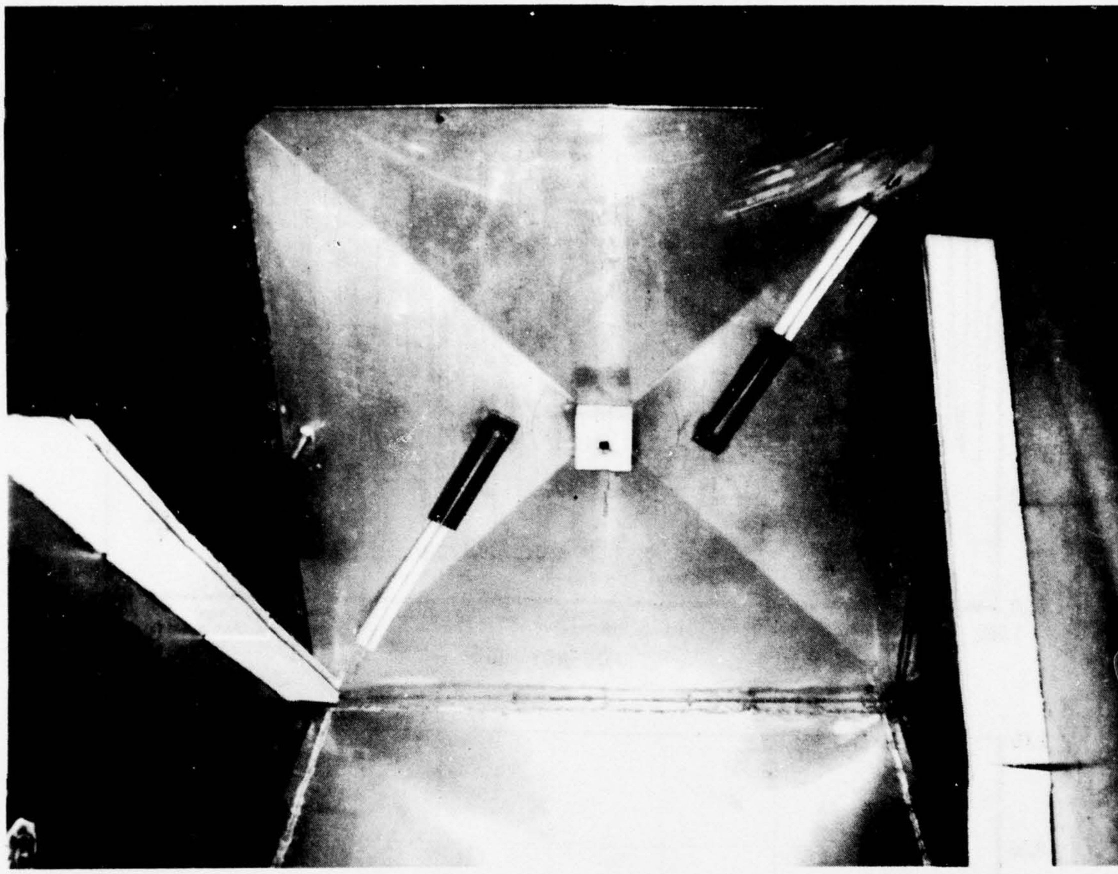
$L_1 = 6.56$ inches (16.66 cm)

$L_2 = 12.44$ inches (31.60 cm)

A photograph of the tapered line installation is shown in Figure 3. Both ends of each antenna are matched to 50 ohm impedance. The taper on the far end of each antenna is terminated with a 50 ohm coaxial load. Thus, through the broadband tapered line impedance transformer, both ends of the antennas are terminated in their own characteristic impedance.

2.4 Test Results

The effect of the tapered line impedance transformer on antenna input impedance can be seen by reference to Figure 4, reflection coefficient vs. frequency for the minimum loss field tuner positions only. Comparison of the before and after



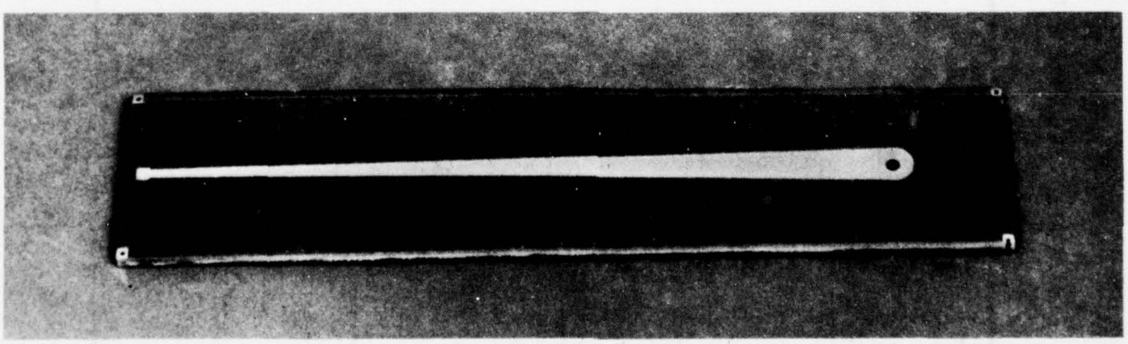
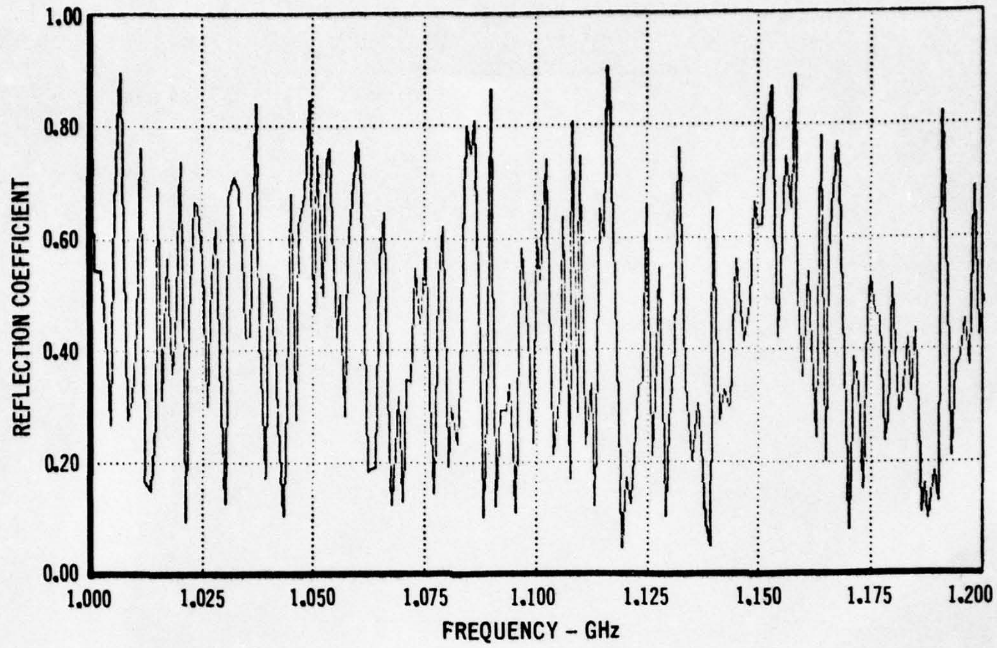


FIGURE 3 TOP: TAPERED LINE INSTALLATION IN EM CHAMBER, SHOWING ANTENNAS IN LOW LOSS POLYSTYRENE FOAM

BOTTOM: CLOSE-UP OF TAPERED LINE IMPEDANCE MATCHING CIRCUIT



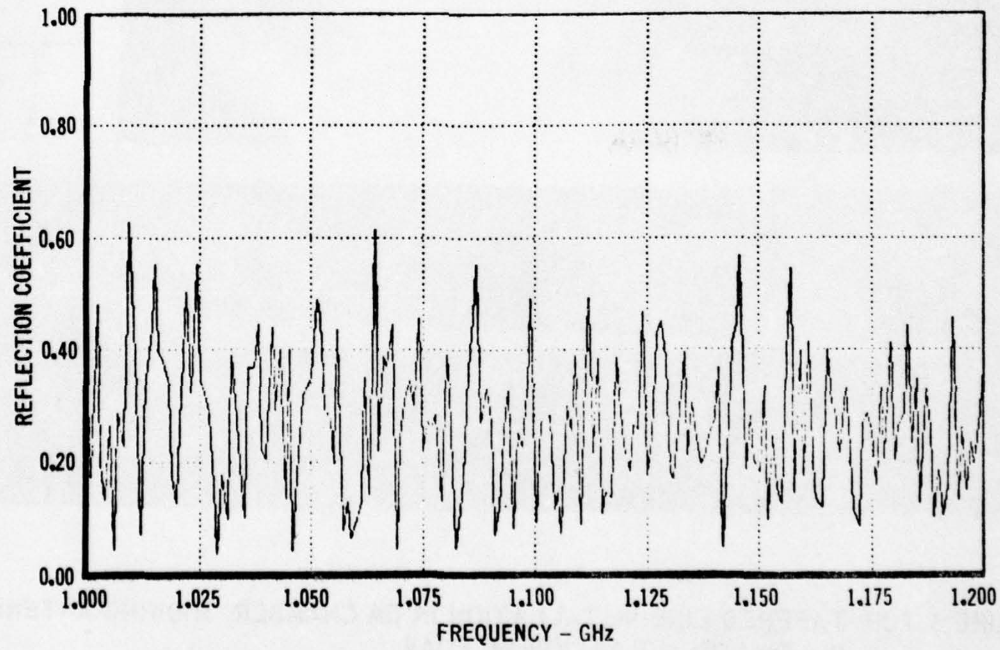


FIGURE 4 REFLECTION COEFFICIENTS IN EM CHAMBER

TOP: UNMATCHED ANTENNAS WITH ORIGINAL FIELD TUNER

BOTTOM: IMPEDANCE-MATCHED ANTENNAS WITH LARGE BENT RECTANGLE FIELD TUNER

conditions shows a considerable improvement in antenna impedance after the tapered lines were installed. Initially, the worst case reflection coefficient was .9 with a mean of .48. The improved antennas show a worst case of about .58 with a mean of .27. Converting the reflection coefficients to equivalent transmission loss shows that the worst case transmission loss has been reduced from 7.2 dB to 1.6 dB, for an improvement of 5.6 dB. This agrees with manual test data we have taken which shows that most improvement attainable by manually tuning the antenna impedance has been a 5 to 6 dB decrease in transmission loss. Some improvement was noted on the higher frequency bands, but the effectiveness of the tapered line transformer was not as great since the antenna impedance match was initially better at the higher frequencies. The electrically larger antenna length and spacing from the chamber at the higher frequencies account for this difference.

3. FIELD TUNER IMPROVEMENTS

Theoretically, if the chamber input and output impedance are matched to the source and load at all frequencies, and the field tuner is capable of adjusting input to output coupling such that polarization, wave direction, and impedance are all optimized at a particular frequency, the output level should depend only on the dissipative I^2R losses within the chamber and antennas. The dissipative loss function is expected to be a relatively smooth curve with gradually increasing loss as frequency is increased due to skin effect on the chamber wall. Hence, the total transmission curve should, in the limit, approach the dissipative loss curve as deficiencies in field tuner performance and antenna impedance matching and other error sources are reduced to zero. The smoothness of the transmission loss curve (described by standard deviation and peak-to-peak value) is thus taken to be the indicator of field tuner relative performance.

All testing associated with the investigation of field tuning improvements was done under computer control, allowing extensive amounts of data to be obtained and analyzed. Computer generated plots were used to evaluate differences in transmission loss curves and the associated statistical data for the many tuning cases examined. A block diagram of the automated system is shown in Figure 5. Flow charts and printouts of the many computer programs developed are contained in Appendix D.

3.1 Field Tuner Size and Shape

Previously, an aluminum field tuner was used as a tuning device in the EM chamber. It consisted of two flat triangular surfaces attached to a rotating shaft at their apexes. The bisector of the apex angle of each triangle lay in the plane perpendicular to the axis of the attached shaft, 180 degrees apart in the plane. The plane of each triangular section was rotated about its bisector

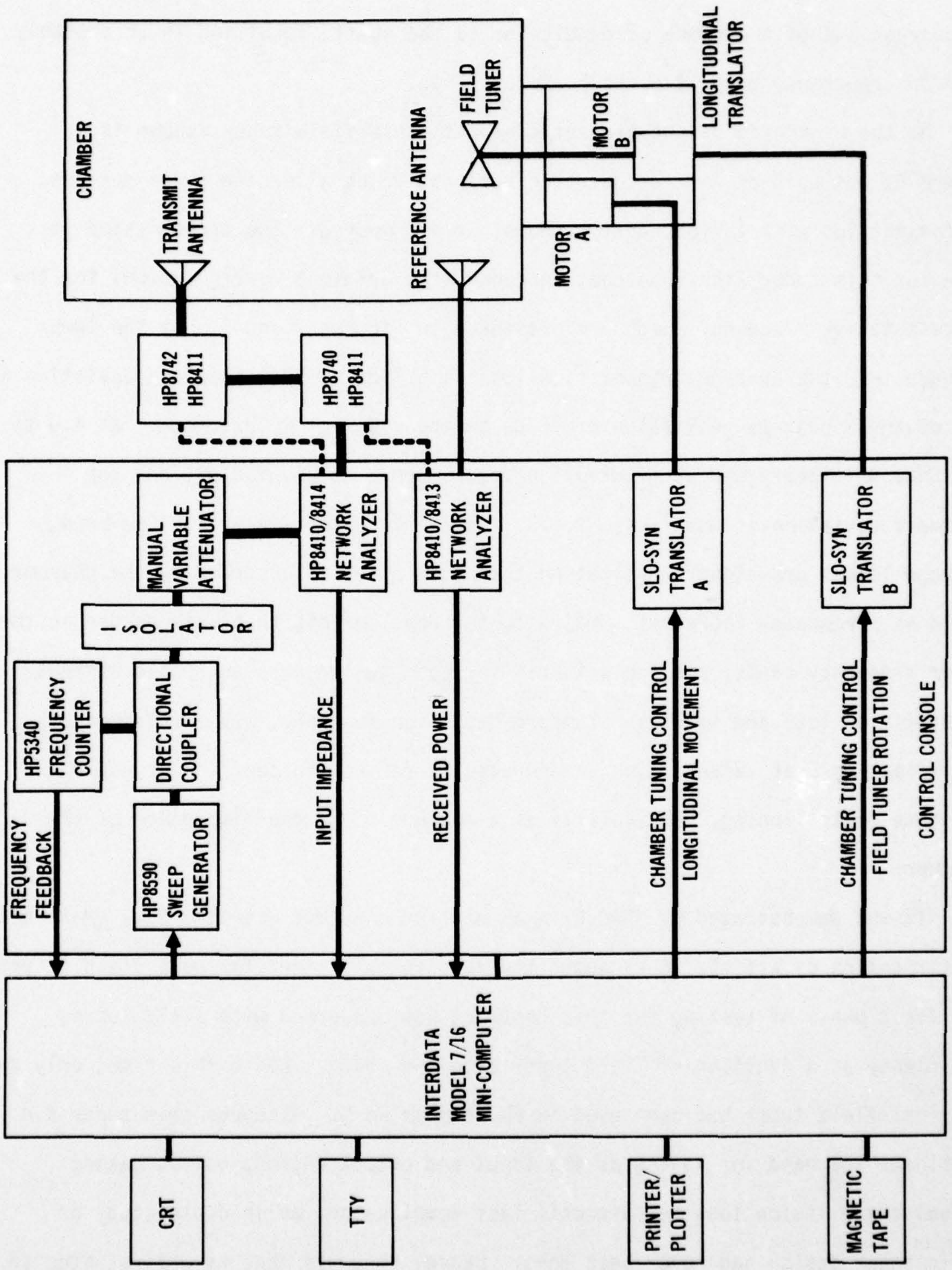


FIGURE 5 AUTOMATED EM CHAMBER MEASURING SYSTEM

45 degrees out of the plane perpendicular to the shaft, resulting in an assembly with an appearance much like the blade of a fan.

At the beginning of the present contract, this field tuner, shown in Figure 6, was used as a reference tuner against which alternate tuner designs, in conjunction with various test methods, were compared. The transmission loss data for this tuner with unmatched antennas (the original configuration) for the representative frequency bands are presented in Figures 7 and 8. At the lower frequencies, the average transmission loss is 5.7 dB, with a standard deviation of 3.4 dB and a peak-to-peak value of 16 dB in the 1.0 to 1.2 GHz range. At 4.0 to 4.2 GHz, this peak-to-peak fluctuation does improve to about 8 dB, and the standard deviation is much less, 1.373. However, in the 7.8 to 8.0 GHz band, average losses are higher, indicating that more power is absorbed by the chamber walls as frequency increases. Major tuning developments then were needed in the lower frequency bands, and the criteria for good tuning were decreased average transmission loss and smallest standard deviation possible, with its attendant small peak-to-peak value. Also, a decrease in reflection coefficient would indicate better tuning, particularly as a measure of matched impedance of the chamber.

It was demonstrated by MDAC-E in an earlier contract with the Navy (Reference 3) that rotation of a field tuner about its axis is sufficient for good field stirring. The first phase of testing for this contract was concerned with field tuning efficiency as a function of field tuner size and shape. Up to this time, only the original field tuner had been used in EM chamber work. Although this tuner did eliminate the need for tuning at the input and output antenna ports, making manual transmission loss measurements less complicated, an in-depth study of field tuner design had never been done. Hence, this was done as a first step to improved field tuning in the EM chamber.

TWIST 45^{0} TO GIVE 8" (20.32 cm) LENGTH AT OUTSIDE EDGE ON TWO PROJECTED VIEWS IN PLANES 90^{0} FROM EACH OTHER.

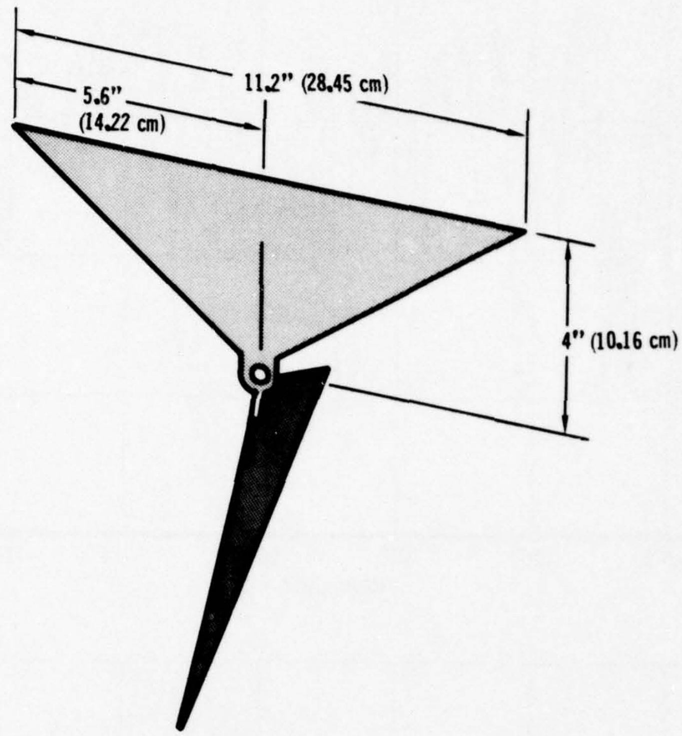


FIGURE 6 ORIGINAL FIELD TUNER

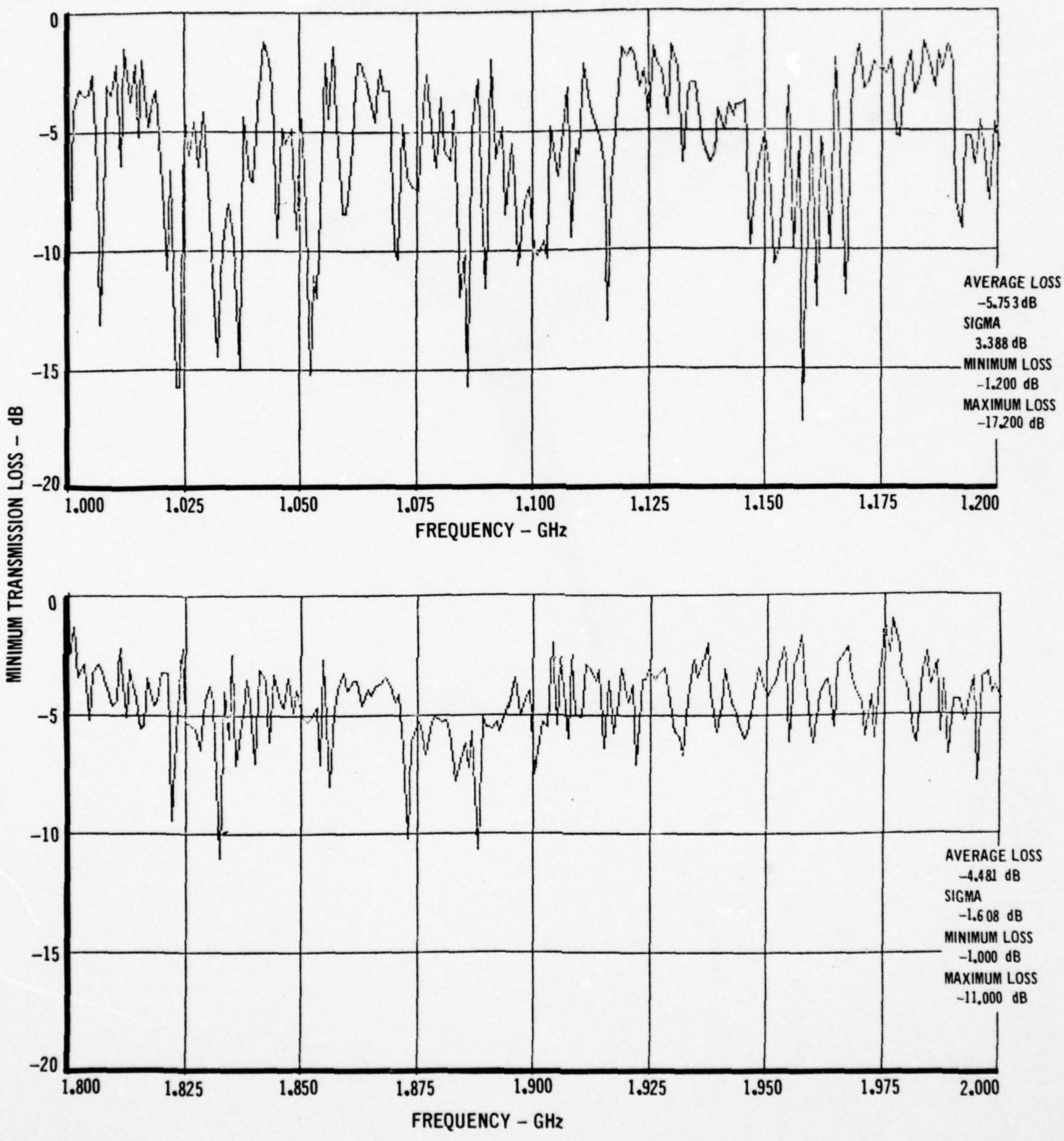


FIGURE 7 MINIMUM TRANSMISSION LOSS, ORIGINAL FIELD TUNER, ROTATION ONLY, UNMATCHED ANTENNAS

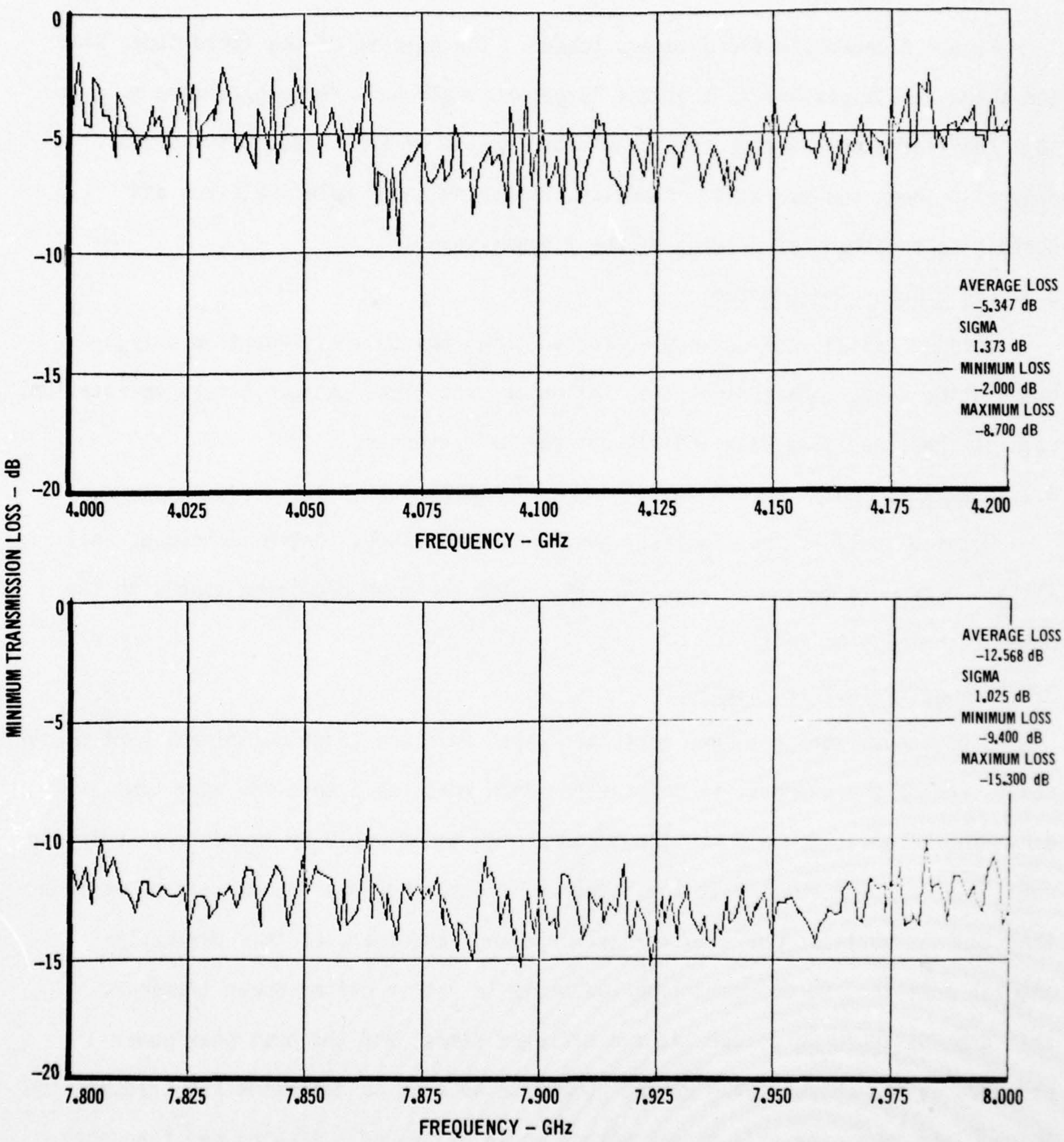


FIGURE 8 MINIMUM TRANSMISSION LOSS, ORIGINAL FIELD TUNER, ROTATION ONLY, UNMATCHED ANTENNAS

Figure 9 shows the field tuners tested. The outcome of the field tuner size and shape investigation was that the large and small bent rectangles were able to stir the fields more efficiently than other tuners of their respective sizes. Figure 10 shows the two bent rectangles, comparing their relative sizes and containing a mechanical drawing of their dimensions.

3.2 Field Tuner Implementation

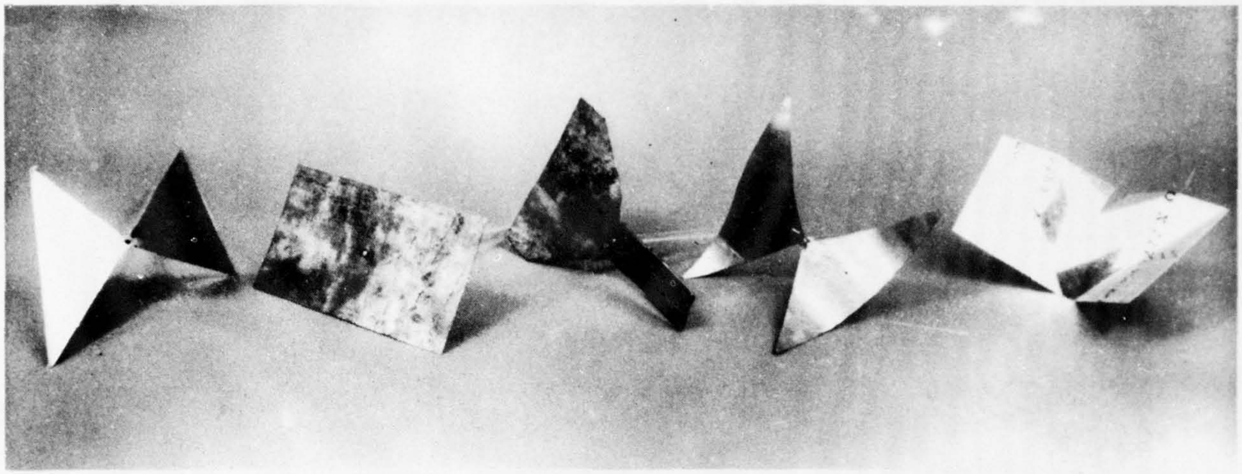
Various tuning schemes were evaluated using the tuners: rotation only, translation only, longitudinal translation and rotation, and two tuners in rotation. Each of these was done with and without matched antennas.

3.2.1 Rotation Only

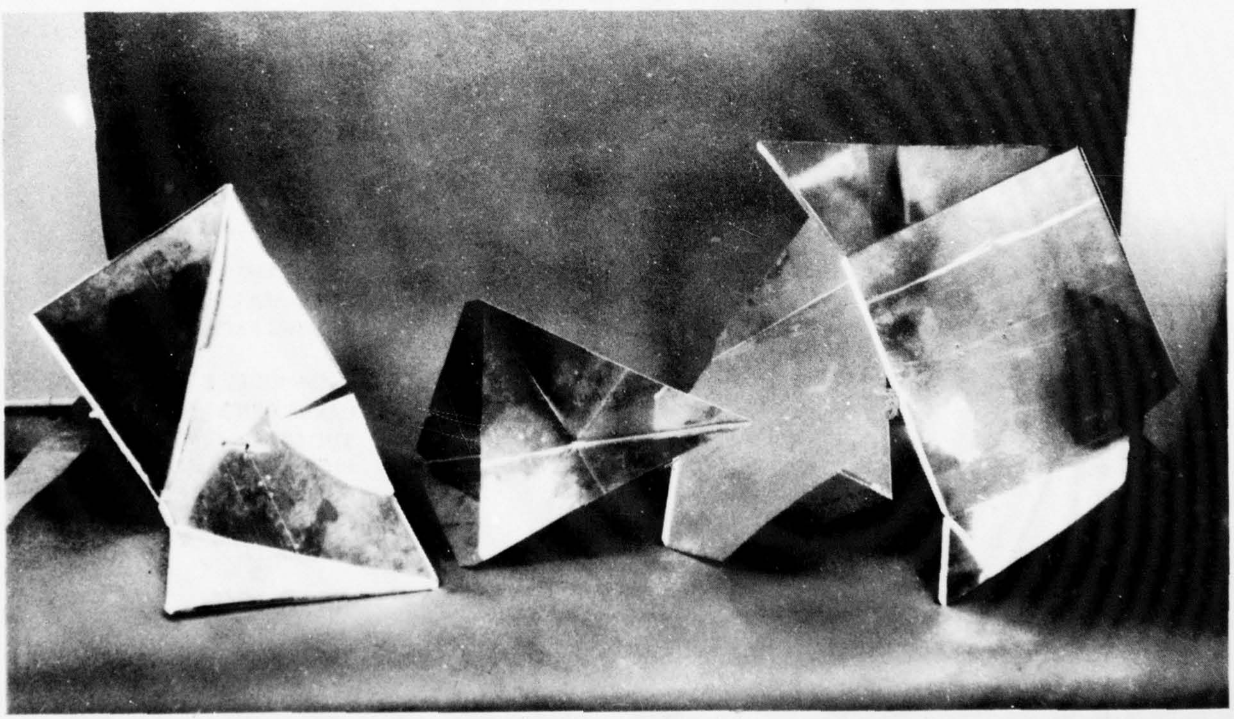
Rotation only is the simplest, hence most desirable, tuning technique. All field tuners were tested in rotation only, with the more promising used with the other techniques as well.

3.2.2 Longitudinal Translation

Some manual work had been performed which involved longitudinal movement of the tuners inside the chamber, in combination with rotation. This was very time consuming because, for a given input power, the tuner would be moved longitudinally until a peak power reading at the output of the chamber was found, rotated at this longitudinal position for a better peak reading, and then, at this particular angular position, moved again longitudinally to obtain better power transfer. This process would be reiterated two or three times, and the best peak power obtained at the output taken as the number to be used to determine the transmission loss. Test time with this manual method would be around 5 minutes per frequency, with one data point gathered in those 5 minutes. This test method, although a valid tuning concept, was time consuming and boring for the individual doing the manual testing. Therefore, during this contract an automated test method was

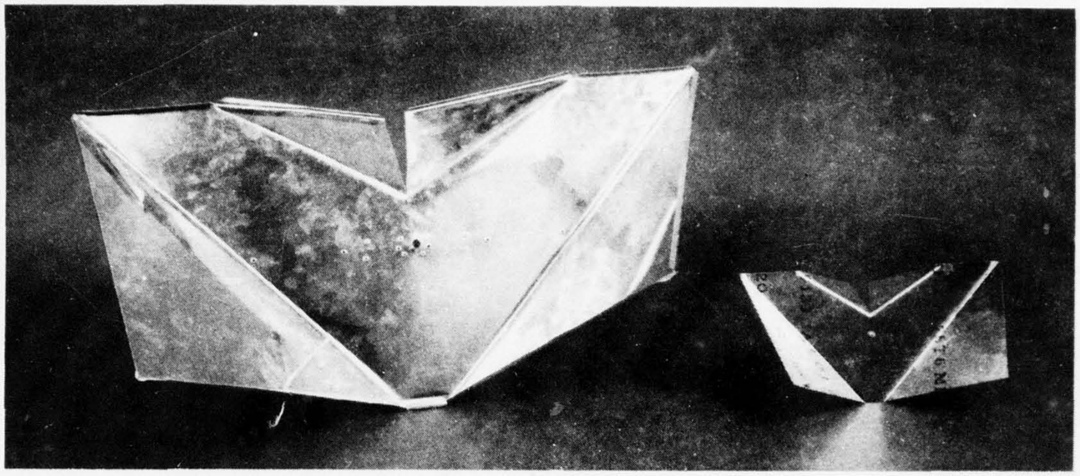


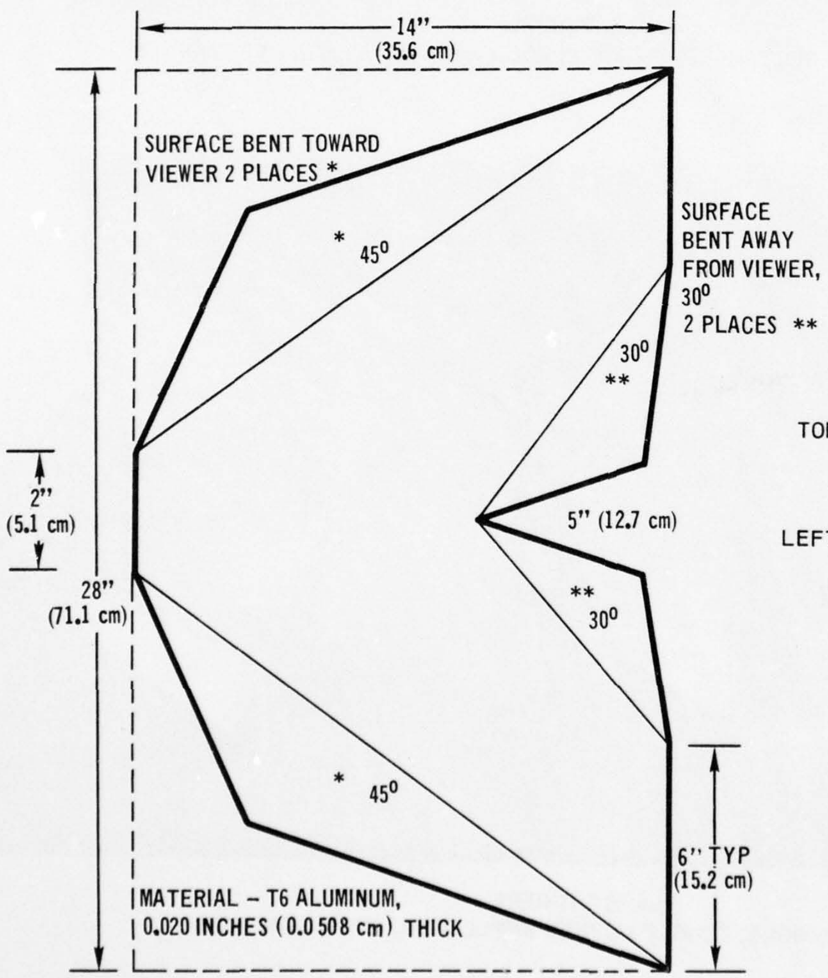
SMALL TUNERS:
ORIGINAL, SLANTED RECTANGLE, SINGLE BLADED, CURVED 'S', BENT RECTANGLE



LARGE TUNERS:
BENT RECTANGLE, DOUBLE CORNER REFLECTOR, MULTI-SURFACED

FIGURE 9 FIELD TUNER SPECIMENS





TOP: LARGE AND SMALL BENT RECTANGLE FIELD TUNERS, SHOWING RELATIVE SIZES.

LEFT: MECHANICAL DRAWING OF LARGE BENT RECTANGLE. THE SMALL TUNER IS 12 INCHES LONG AND 6 INCHES WIDE (30.4 X 15.2 cm)

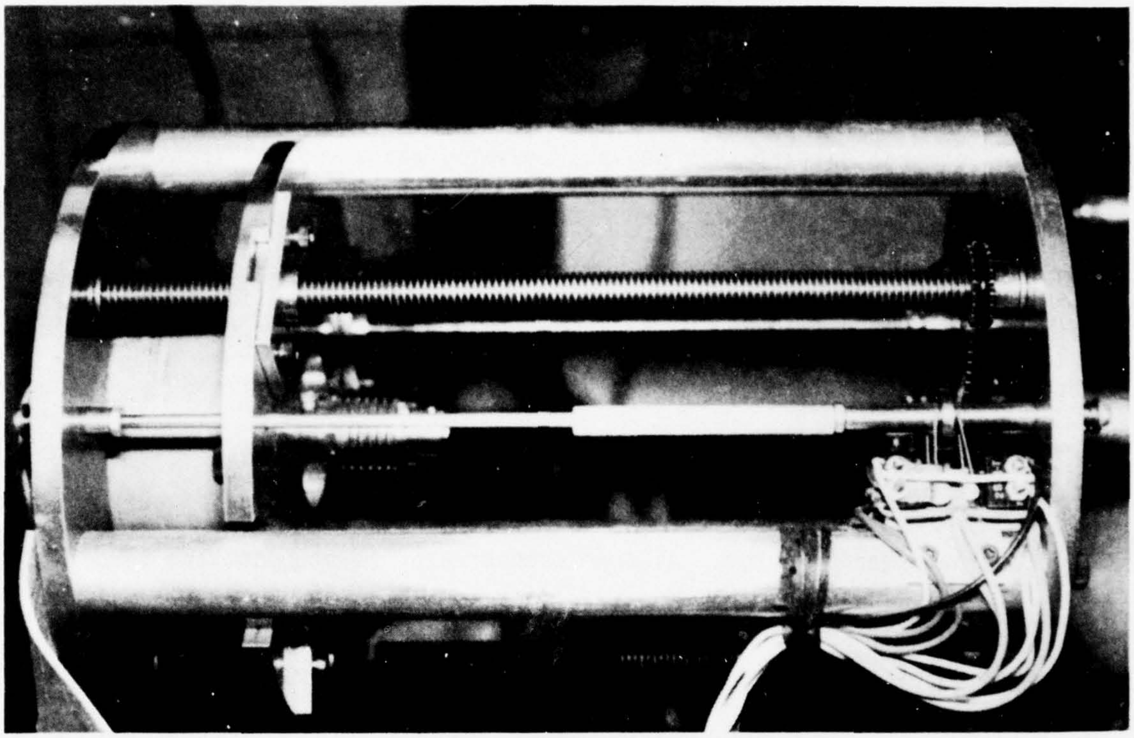
FIGURE 10 BENT RECTANGLE FIELD TUNER

developed to study the effects of longitudinal translation of various tuners, enabling very precise positioning of the tuner.

An integral part of this phase of testing was a special longitudinal translating mechanism that allows about 6 inches (15 cm) of travel which was designed and built for the automated system. The longitudinal translator is pictured in Figure 11 along with a mechanical drawing. The rotational stepper motor is mounted on a moving carrier with the shaft of the field tuner coupled directly to the shaft of the motor. This assembly, in turn, is threaded onto three jack screws, each having a pulley connected by a "no slip" belt to the longitudinal stepper motor. As this second motor is stepped, the three jack screws carry the field tuner motor assembly back and forth, providing longitudinal translation of the tuner. When used with the rotation motor, the number of test points vary from 3000 to 4500, depending upon the test frequency. (The higher the frequency, the shorter the wavelength, and hence, an increased number of test distances in 15 cm.)

3.3 Practical Considerations

The practical low frequency limit of the EM chamber before the beginning of this contract was about 2.0 GHz, with fairly good stirring at frequencies up to 10 GHz. The field tuning from 1.0 to 2.0 GHz was not adequate, and it was felt by MDAC-E and NSWC that tuning improvements in all bands could be made by using techniques discussed above, with the most significant progress taking place at the lower frequencies. Therefore, four frequency bands, each 200 MHz wide, were chosen as representative samples at which to test for field tuning improvements. Two of the bands, 1.0 to 1.2 GHz and 1.8 to 2.0 GHz, were selected to observe effects at the low frequency limit of the EM chamber, since room for the most improvement was here. The other two bands, 4.0 to 4.2 GHz and 7.8 to 8.0 GHz,



TOP: LONGITUDINAL TRANSLATOR MOUNTED ON SIDE OF EM CHAMBER
BOTTOM: MECHANICAL DRAWING OF THE DEVICE

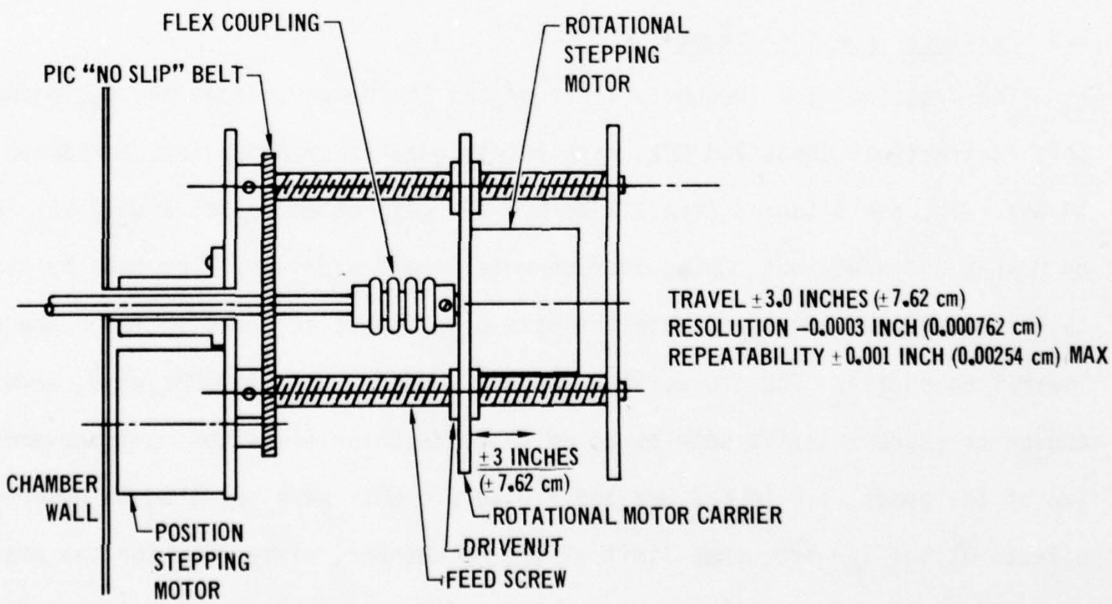


FIGURE 11 LONGITUDINAL AND ROTATIONAL STIRRING MECHANISM

were monitored to make sure nothing untoward was happening at high frequencies as tuning improvements at lower frequencies were made.

In each of these 200 MHz bands, data were taken at every 1 MHz (sometimes, every 2 MHz). While these many data points were considered necessary in developing good tuning techniques, one must not expect to have to test a large number of frequencies very close together in actual shielding effectiveness or EM susceptibility tests, particularly when good tuning has been demonstrated, except perhaps in the vicinity of resonant frequencies of the system under test.

3.4 Test Results

The field tuner improvements were evaluated for an empty chamber and for a representative piece of equipment in the chamber. A new low frequency limit for the 3 x 3 x 5 foot (0.91 x 0.91 x 1.52 m) chamber was identified and a discussion of test times is presented.

3.4.1 Empty Chamber

Fourteen tuning configurations were evaluated in the empty chamber for field stirring improvements. The results are summarized in Table I, where they are ranked in order of tuning efficiencies. In general, test cases with impedance matched antennas surpassed the unmatched cases, and those test schemes that used more complex tuning implementations had lower transmission losses, standard deviations, and peak-to-peak values.

Figure 12 is an example of the data from which the statistics in Table I were generated. All the plots are to be found in Appendix C. While the table is a convenient presentation of the results of testing, some caution is in order. As seen in the 7.8 to 8.0 GHz band of the figure, there is a negative slope. This adversely affects the statistics for those cases that exhibit this slope, for the

TABLE I. TRANSMISSION LOSS STATISTICS FOR CONFIGURATIONS TESTED IN EMPTY CHAMBER

CONFIGURATION	1.0-1.2 GHz			1.8-2.0 GHz			4.0-4.2 GHz			7.8-8.0 GHz		
	Ave	Sigma	P-P	Ave	Sigma	P-P	Ave	Sigma	P-P	Ave	Sigma	P-P
LBR + SBR In Rotation, Matched	-0.925	0.299	1.7	Not Tested			-3.713	0.519	2.9	Not Tested		
LBR, Rotation + Translation, Matched	-2.132	0.665	3.7	Not Tested			-3.860	0.550	3.2	Not Tested		
LBR, Rotation, Matched	-2.190	0.824	4.1	-2.226	0.559	3.3	-5.617	0.671	3.3	-12.372	1.410	7.6
Original, Rotation + Translation, Unmatched	-3.064	1.542	8.6	-2.564	0.737	3.4	-4.778	0.949	4.7	-9.577	0.719	4.1
SBR, Rotation, Matched	-3.724	1.399	8.6	-2.805	0.956	4.1	-5.886	0.860	4.4	-12.376	1.304	4.7
LBR, Rotation, Unmatched	-3.668	1.552	8.2	-3.336	0.856	4.2	-7.755	0.896	5.5	-12.295	0.852	5.3
Large Multi-Surfaced, Rotation, Unmatched	-3.782	1.653	7.3	-3.701	0.925	5.1	-7.749	0.985	5.2	-12.430	0.928	5.5
SBR, Rotation, Unmatched	-4.44	2.563	12.9	-4.177	1.346	7.1	-5.673	1.308	7.7	-12.476	1.112	5.8
Large Circular, Translation, Unmatched	-4.394	2.599	14.00	-4.66	1.757	9.6	Not Tested			Not Tested		
Curved "S", Rotation, Unmatched	-4.708	2.783	14.8	-4.152	1.44	7.3	-5.528	1.138	6.2	-13.164	1.158	6.1
Slanted Rectangle, Rotation, Unmatched	-4.843	3.060	17.3	-4.118	1.358	7.1	-5.274	1.279	6.7	-12.866	1.242	7.5
Single-Bladed Fan, Rotation, Unmatched	-4.535	3.302	16.4	-3.805	1.310	7.4	-5.903	1.224	6.4	-12.783	1.171	6.4
Original, Rotation, Unmatched	-5.753	3.388	16.00	-4.491	1.608	10.00	-5.347	1.373	7.7	-12.568	1.025	5.9
Original, Translation, Unmatched	-5.640	4.033	26.8	-4.963	1.939	8.8	-6.850	0.909	4.2	-11.575	1.001	5.4

LBR - LARGE BENT RECTANGLE
SBR - SMALL BENT RECTANGLE

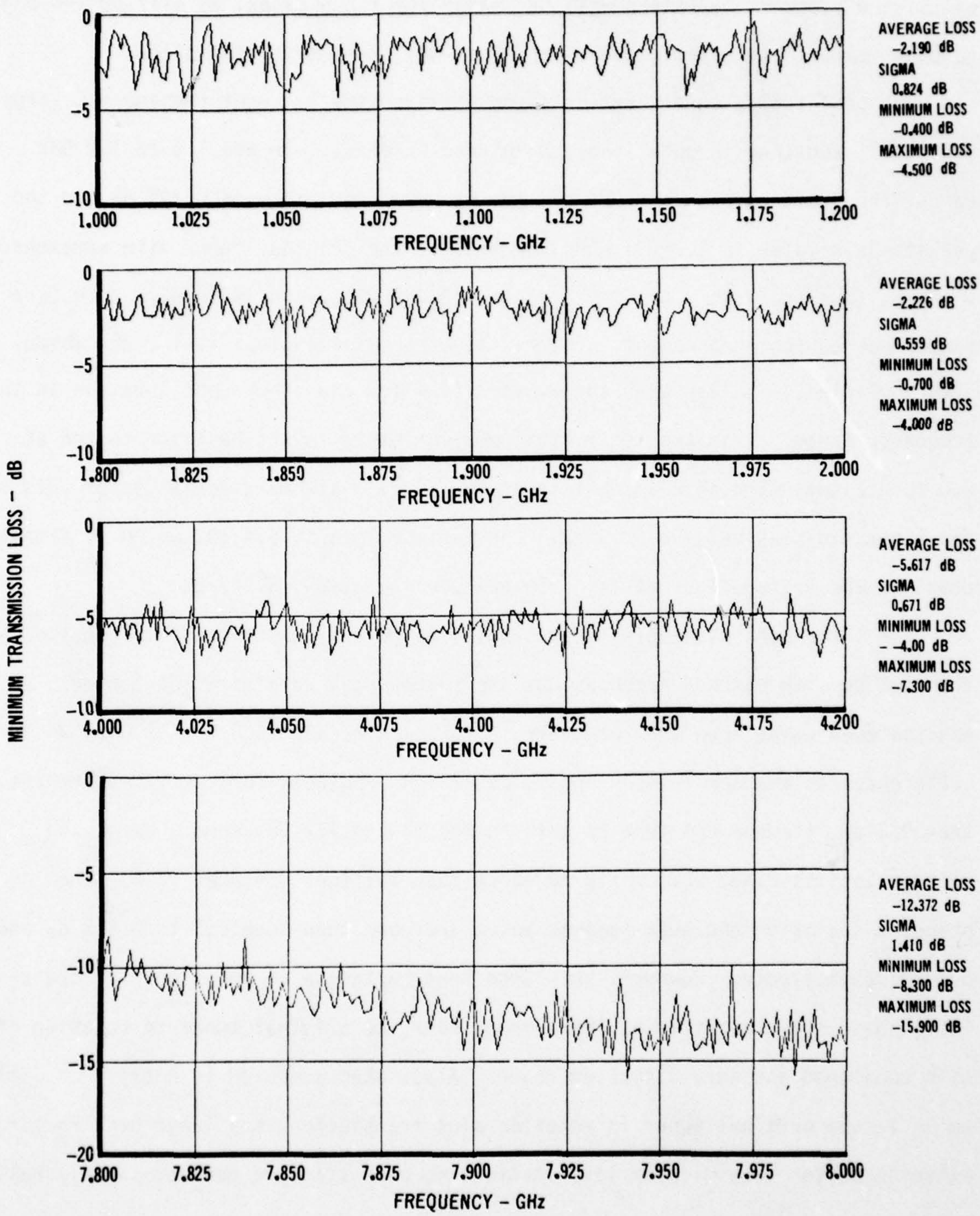


FIGURE 12 TRANSMISSION LOSS, LARGE BENT RECTANGLE, ROTATION ONLY, MATCHED ANTENNAS

calculated standard deviation will be higher for these cases, as will be the peak-to-peak values. In effect, these represent the worst case statistics.

The best tuning configuration found utilized the two bent rectangles, large and small, together in rotation with matched antennas. In the 1.0 to 1.2 GHz range, the average loss is 0.925 dB, the standard deviation is 0.299 dB and the peak-to-peak value is 1.7 dB; when compared to the original tuner with unmatched antennas (average loss = 5.753 dB, sigma = 3.388 dB, p-p = 16.00 dB), this is a tremendous tuning enhancement. The maximum transmission loss is 1.9 dB, which, as seen in Table I, is less than the average loss for any other configuration in this frequency range. This two-tuner configuration was also the best one tested at 4.0 to 4.2 GHz, with an average loss of 3.713 dB, a standard deviation of .519 dB, and a peak-to-peak value of 2.9 dB. The maximum loss is 5.4 dB, which is almost equal to the average loss of the original configuration, 5.347 dB.

The large bent rectangle (best single field tuner discovered) in rotation plus translation with matched antennas was the second best configuration tested. While not too much worse than the two-tuner in rotation case at 4.0 to 4.2 GHz, where differences in average loss, standard deviation, and peak-to-peak value are less than 0.3 dB, it does not tune as well in the 1.0 to 1.2 GHz band. Here, the average loss is 2.132 dB, or 1.2 dB worse than for the two-tuner case. The standard deviation and peak-to-peak value are more than doubled, to 0.665 dB and 3.7 dB respectively. However, the large bent rectangle in rotation plus translation does offer significant improvement over the original tuner in rotation only with unmatched antennas discussed above. Also, when compared to entry 4 of Table I, which is the original tuner in rotation plus translation, the large bent rectangle exhibits better transmission loss statistics, with standard deviations only half as large.

Finally, both the small and large bent rectangle, entries 3 and 5 of Table I, yield acceptable results in rotation only with matched antennas when compared to

the original tuner in rotation only with unmatched antennas, entry 13. At 1.0 to 1.2 GHz, the large bent rectangle in rotation only has an average loss of 2.190 dB, and a standard deviation of 0.824 dB, both numbers being within 0.16 dB of those for the same tuner in rotation plus translation; one tunes as well as the other here. At 4.0 to 4.2 GHz, there is only 0.12 dB difference in the standard deviation, indicating that, again, losses in the EM chamber using the large bent rectangle in rotation alone can be predicted with the same degree of confidence as with rotation plus translation, with only an overall decrease in average loss of about 2.0 dB being the major difference in the two configurations. The comments on the improved tuning ability of the two-tuner scheme over the rotation and translation of the large bent rectangle, stated in the preceeding paragraph, apply as well to the rotation only case.

As noted in Table I, the small bent rectangle in rotation only is clearly inferior to the large bent rectangle in the two lower frequency bands. However, at 4.0 to 4.2 GHz and 7.8 to 8.0 GHz, there are virtually no differences in performance, with average losses and standard deviations being within 0.2 dB in both cases. Only the peak-to-peak values are very dissimilar in the 7.8 to 8.0 GHz band, being 7.6 dB for the large bent rectangle and 4.7 dB for the small bent rectangle, a difference of 2.9 dB, although the standard deviations, 1.410 dB and 1.304 dB vary by only 0.1 dB.

3.4.2 Effects of Equipment in Chamber

While this contract was primarily concerned with reducing the transmission loss variations as a function of frequency through the empty EM chamber, there will be equipment present in the chamber during susceptibility testing. Therefore, an unpowered Boonton power meter [8 1/4" (20.9 cm)W x 5 1/8" (13 cm)H x 11"(27.9 cm)L] was placed in the chamber to simulate an actual EM susceptibility test condition,

and a number of tests were run to determine what effects, if any, would be produced. Figure 13 shows the meter in the chamber and Table II summarizes the results. When compared to the corresponding configuration for an empty chamber, shown in Table I, the addition of equipment tends to raise the transmission losses through the chamber, with the degradation most prominent in the 1.0 to 1.2 GHz and 1.8 to 2.0 GHz ranges.

The two-tuner configuration in rotation only was the best tuning scheme for equipment in the chamber, as it was for an empty chamber. It was the best at 1.0 to 1.2 GHz, where the average loss was 4.308 dB, the standard deviation is 0.751 dB, and the peak-to-peak number is 4.5 dB. Compare this to all the other cases in Table II. At 4.0 to 4.2 GHz, the two-tuner scheme is just a little better than the large bent rectangle in rotation with and without longitudinal translation.

The performance of the chamber with equipment before the paddlewheel and antenna improvements were made is worth noting here. Figure 14 shows the measured transmission loss in the two low frequency bands. An overriding component with a frequency of approximately 70 MHz is clearly present. Since this effect is removed by the new antenna design, it is apparent that poor design can severely degrade the performance of the chamber.

3.4.3 Low Frequency Limits

After the peak-to-peak variations in transmission loss versus frequency had been reduced in the 1.0 to 10.0 GHz range with tuning improvements tested under this contract, transmission losses for frequencies below 1.0 GHz were obtained using the large bent rectangle in rotation with matched antennas. It appears that the lower limit is about 800 MHz; everything below here is as bad as the tuning in the chamber was at 1.0 - 2.0 GHz with the original tuner and unmatched antennas. From 800 to 1000 MHz, although the peak-to-peak value and the average

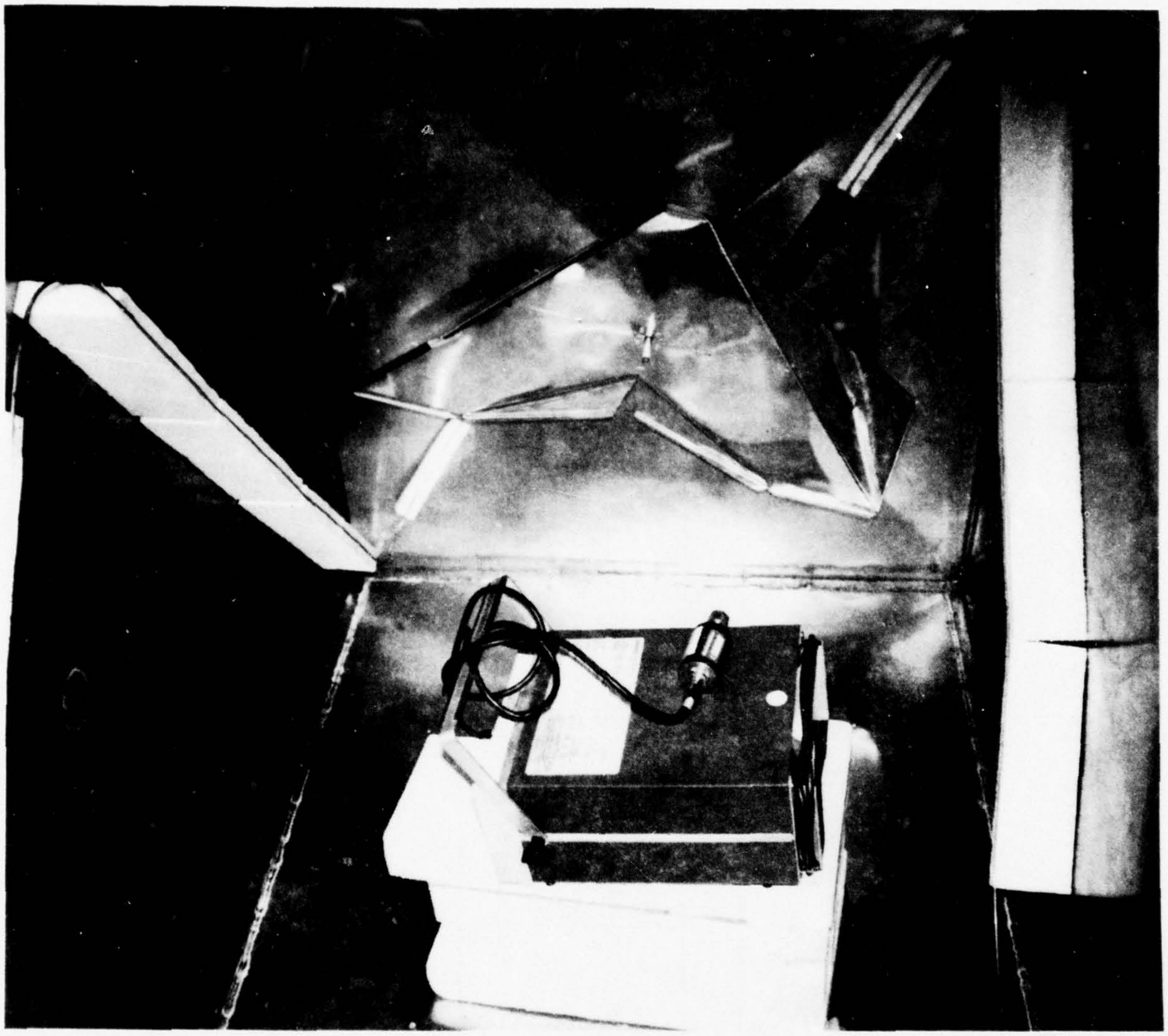


FIGURE 13 EM CHAMBER, SHOWING BOONTON POWER METER INSIDE. THE FIELD TUNER ON THE FAR END IS THE LARGE BENT RECTANGLE

TABLE II. TRANSMISSION LOSS STATISTICS FOR CONFIGURATIONS TESTED WITH EQUIPMENT IN CHAMBER

	1.0-1.2 GHz			1.8-2.0 GHz			4.0-4.2 GHz			7.8-8.0 GHz		
	Ave	Sigma	P-P	Ave	Sigma	P-P	Ave	Sigma	P-P	Ave	Sigma	P-P
LBR + SBR, Rotation, Matched	-4.308	0.751	4.5	Not Tested			-7.571	0.727	3.8	Not Tested		
LBR, Rotation + Translation, Matched	-4.862	1.135	5.5	Not Tested			-7.722	0.762	3.9	Not Tested		
LBR, Rotation, Matched	-5.096	1.210	6.5	-5.211	0.851	4.4	-9.531	0.841	4.3	-16.813	1.630	8.1
SBR, Rotation, Matched	-6.347	1.814	10.9	-6.904	1.365	6.7	-11.669	1.060	5.4	-17.602	1.588	7.7
LBR, Rotation, Unmatched	-9.314	3.609	16.5	-7.890	1.554	8.2	-11.418	0.972	7.3	-15.240	0.972	4.9

LBR - LARGE BENT RECTANGLE
SBR - SMALL BENT RECTANGLE

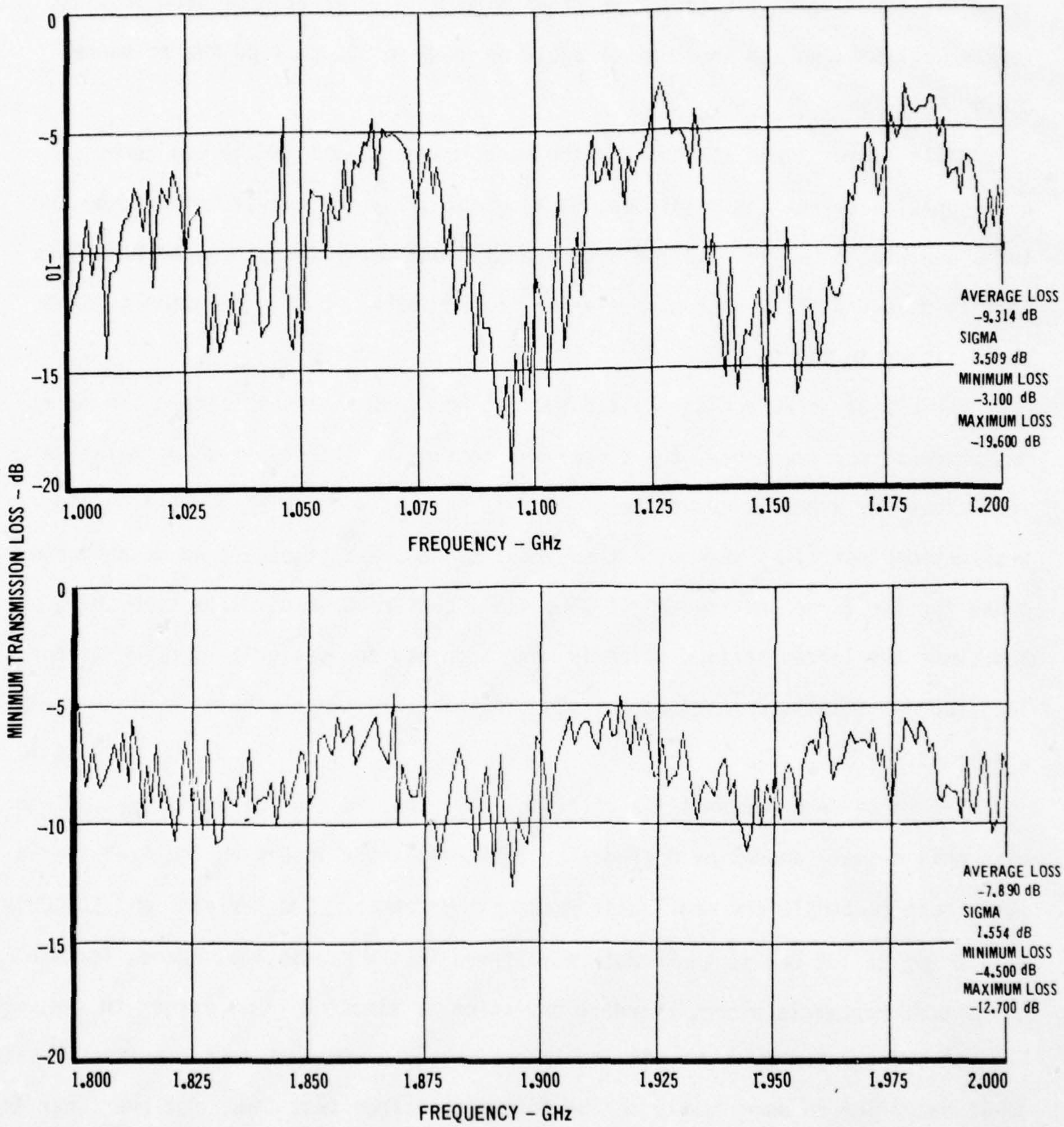


FIGURE 14 MINIMUM TRANSMISSION LOSS, LARGE BENT RECTANGLE, ROTATION ONLY, UNMATCHED ANTENNA, EQUIPMENT IN CHAMBER

are greater than from 1.0 to 1.2 GHz (See Figure 15), the transmission loss is fairly well behaved and the chamber could be used at 800 to 1000 MHz if needed.

3.4.4 Test Times

While Tables I and II indicate the best tuning scheme is the two tuner configuration (large and small bent rectangle in rotation only), followed by the large bent rectangle in rotation plus translation, these two tuning methods have certain disadvantages, not only relative to each other, but in relation to other cases listed in the tables.

The primary drawback to the top two tuning schemes is test time. The more measurements per frequency, the longer the test time. Table III shows relative test times for a 200 frequency test. The large bent rectangle in rotation plus translation test times vary with frequency; since these times are no better than those for the large bent rectangle plus small bent rectangle in rotation only, and since the latter configuration is more accurate and easier to implement (no longitudinal translator need be built), the two field tuner scheme is clearly more practical.

The large bent rectangle in rotation only offers a considerable time savings with only a small amount of degradation in transmission loss when compared to the large bent rectangle and small bent rectangle together. See Tables I and II. Only at 1.0 GHz to 1.2 GHz is there much difference in the statistics, where, for the large bent rectangle alone, standard deviation is almost 3 times larger in the empty chamber and 1.5 times larger with equipment present. In most test situations, this small sacrifice in uncertainty can be tolerated, since test times for one tuner in rotation alone are over 100 times shorter than those where two tuners are used together or translation is added to rotation. The small bent rectangle in rotation only is included in Table III, for it can be rotated twice as fast as the large bent rectangle, due to its smaller size and the accompanying decreased torque

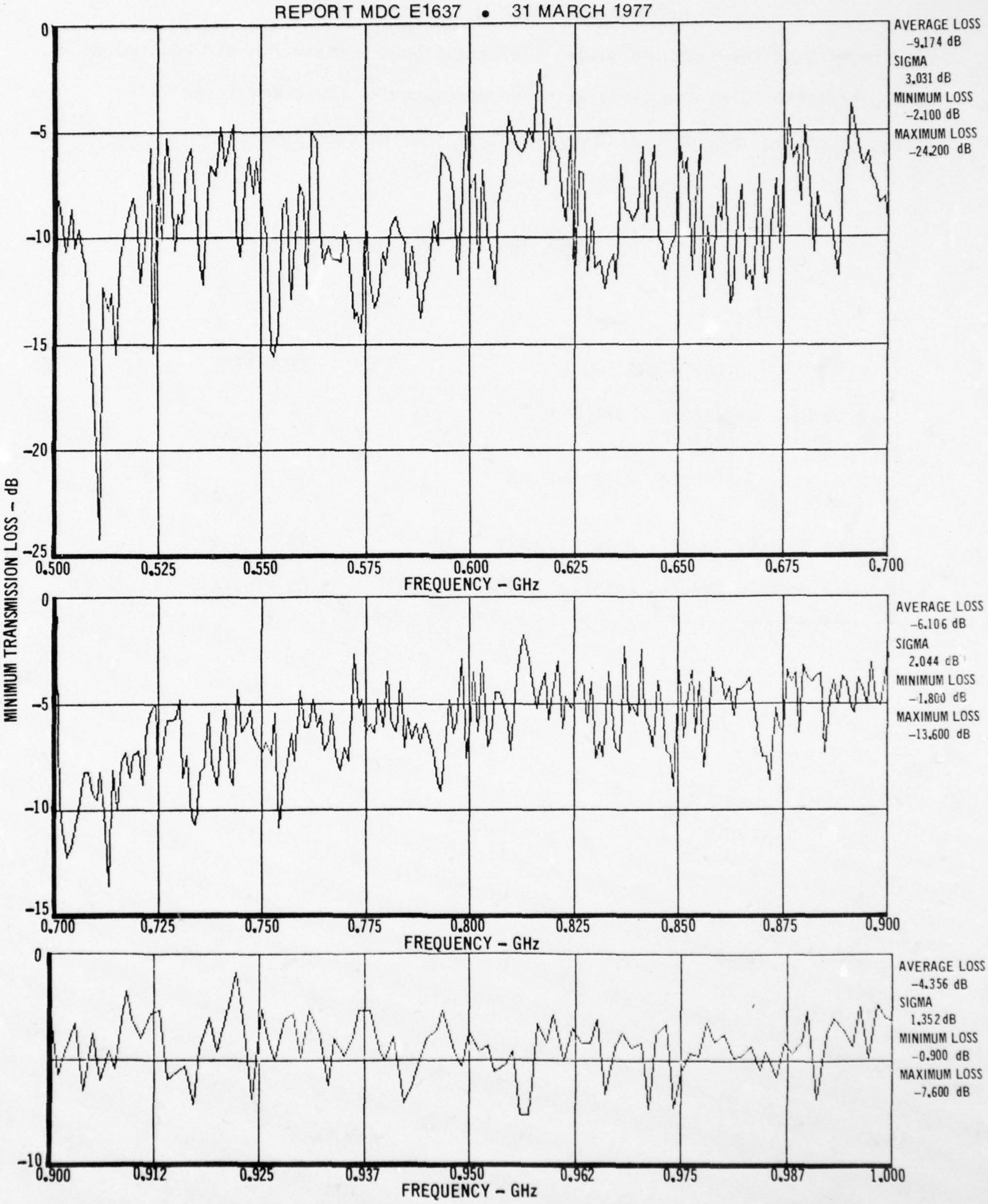


FIGURE 15 LOW FREQUENCY LIMIT, MINIMUM TRANSMISSION LOSS, LARGE BENT RECTANGLE, ROTATION ONLY, MATCHED ANTENNAS

requirements on the stepping motor. The small bent rectangle could be used in some applications, particularly at higher frequencies where the large bent rectangle offers little or no improvement in transmission loss.

TABLE III

Test Times for 200 Frequencies

CONFIGURATION	TEST TIME
Large Bent Rectangle/Small Bent Rectangle in Rotation	40 hours
Large Bent Rectangle, Rotation and Translation	35-50 hours
Large Bent Rectangle, Rotation only	40 minutes
Small Bent Rectangle, Rotation only	20 minutes

4. EVALUATION OF HALFWAVE DIPOLE MODEL

Electronic system EMV hardness designs are based upon an estimate of the amount of power which would be picked up from the electromagnetic environment by an unshielded wire or cable. Previous work (Reference 10) has indicated that the peak pickup level can be predicted by the effective aperture of a matched halfwave dipole antenna

$$A_e = .13\,\lambda^2$$

This relationship obviously breaks down as the frequency approaches zero ($\lambda \to \infty$), so an estimate of its lower frequency limit is needed. An experiment using two lengths of twisted wire pairs was conducted to measure peak effective apertures at eight frequencies between 100 MHz and 2 GHz.

A fiber optics system was used to transmit measured values from the test sample to the receiving instrumentation. Figure 16 shows the test configuration. Both test samples (a two foot and a ten foot cable) were terminated on one end with 50 ohms and the other end with a detector connected to the fiber optics system. The test samples were mounted on a wooden support and rotated in azimuth to produce antenna patterns. See Figure 17. Conical cuts were taken to examine the three dimensional pattern more closely. The number of cuts ranged from seven at 115 MHz where the pattern lobes were broad to 19 at 2000 MHz (every five degrees in elevation) where the lobe structure was more pronounced. See Figure 18. A total of 213 patterns were measured for the two test samples and eight test frequencies.

The peak pickup levels are displayed in Table IV. For clarity, all values have been referenced to a one watt per square meter power density. Also shown is the calculated peak pickup of a matched halfwave dipole. A least squares regression calculation shows a $f^{-2.006}$ dependence for the two foot (.61 m) cable and a $f^{-2.117}$

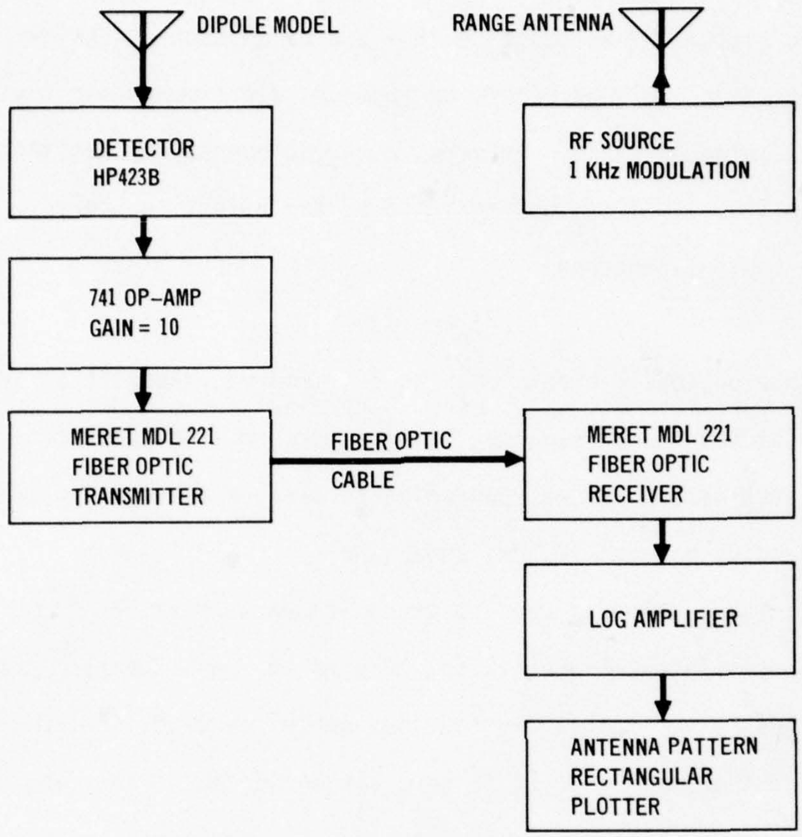


FIGURE 16 DIPOLE MODEL TEST SETUP

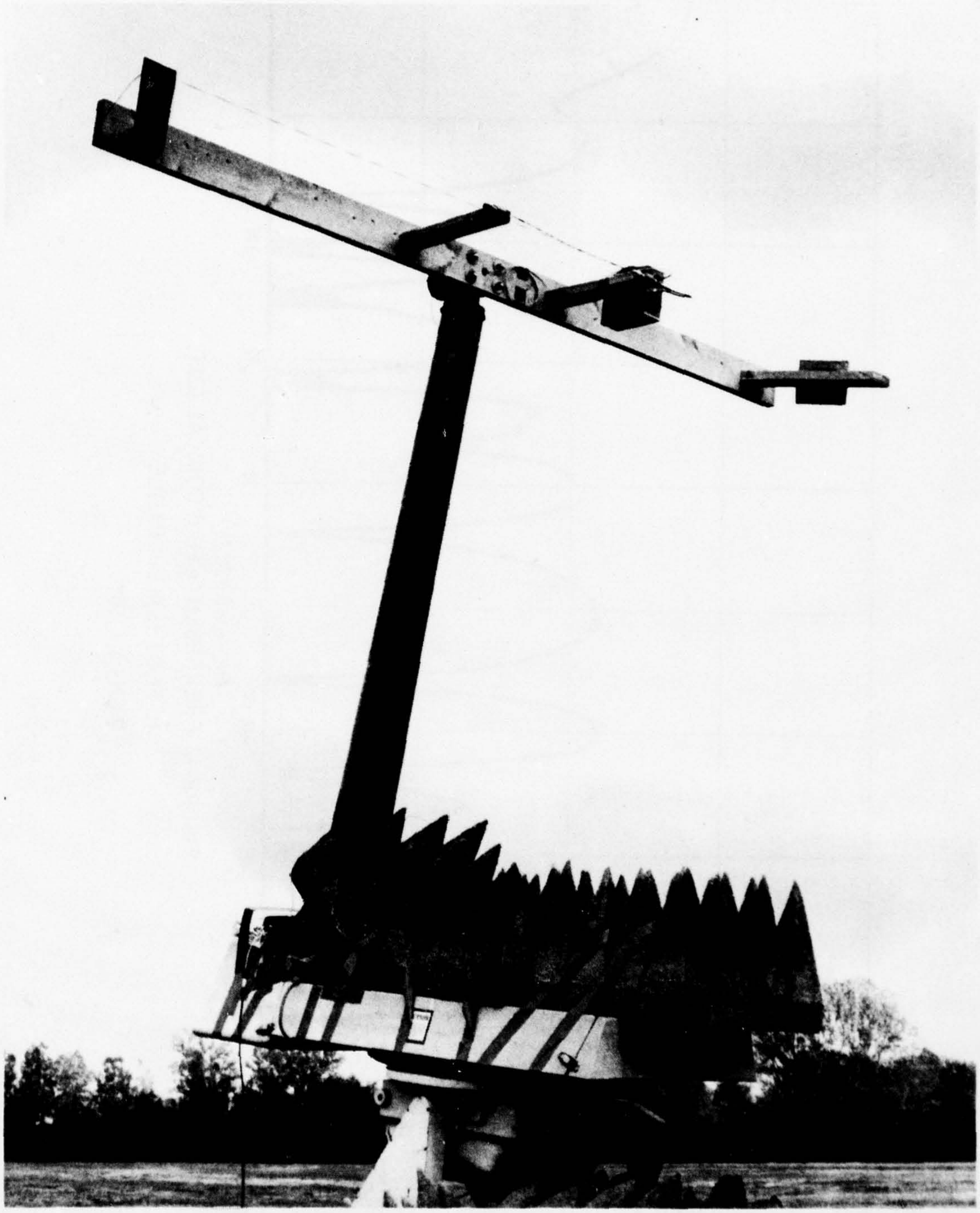


FIGURE 17 10 FOOT (305 cm) TWISTED-WIRE PAIR ON TEST PEDESTAL AT ANTENNA RANGE

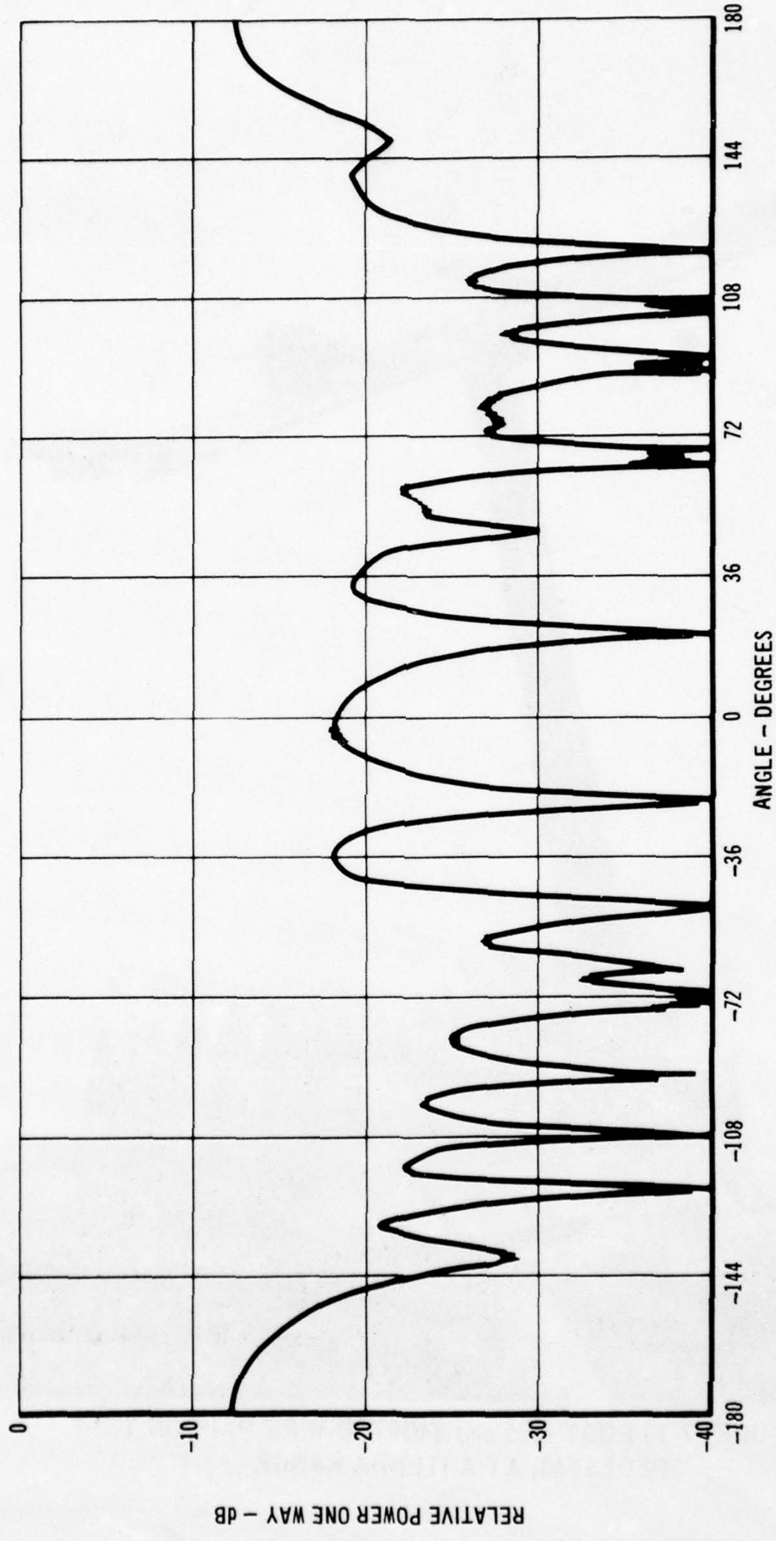


FIGURE 18 PREPRESENTATIVE CONICAL CUT,
10 FOOT (305 cm) CABLE
2 GHz, θ = 50°

Table IV

Peak Power Received Referenced to a 1 Watt/m^2 Field

Frequency	2 foot (.61 m) cable	10 foot (3.05 m) cable	$\lambda/2$ Dipole
0.115 GHz	19.5 dBm	22.3 dBm	29.5 dBm
0.220	16.1	18.9	23.8
0.300	24.8	18.8	21.1
0.400	15.1	22.3	18.6
0.600	10.5	13.6	15.6
0.900	5.5	-0.3	11.6
1.300	-0.7	1.6	8.4
2.00	-0.7	1.2	4.7

dependence for the 10 foot (3.05 m) cable. By constraining the frequency dependence to exactly f^{-2} for comparison to a halfwave dipole the following least square equations result:

$$P_R(\text{dBm}) = 6.53 + 10 \log f^{-2} \qquad \text{(2 foot (.61 m) cable)}$$

$$P_R(\text{dBm}) = 6.64 + 10 \log f^{-2} \qquad \text{(10 foot (3.05 m) cable)}$$

$$P_R(\text{dBm}) = 10.7 + 10 \log f^{-2} \qquad (\lambda/2 \text{ dipole})$$

where a 1 watt/m^2 field is assumed and f is measured in GHz. The standard error is given by

$$S.E. = \sqrt{\frac{\Sigma d^2}{N}}$$

where d = difference between predicted value and measured value,

N = number of points.

For the 2 foot (0.61 m) cable, S.E. = 4.2 dB; for the 10 foot (3.05 m) cable, S.E. = 4.3 dB. Thus the expressions for pickup on the two cables are within a fraction of a decibel of each other and within one standard error of the halfwave dipole expression.

System designers can use the halfwave dipole expression to estimate the pickup on unshielded wires and cables with fair confidence over the frequency interval beginning at 100 MHz. When this pickup information is combined with a knowledge of component susceptibility, minimum shielding specifications can be derived which will insure no unwanted EM responses will occur in the system exposed to high power EM fields.

5. CONCLUSIONS AND RECOMMENDATIONS

The concept that a multi-mode EM test chamber can be designed and built to produce optimum coupling from input to output has been amply demonstrated. To apply this test capability to practical problems of determining shielding effectiveness or system vulnerability, it is necessary to assume that the optimum coupling will also exist between the input and the sample under test. This assumption gains credence from the thoroughness of the tuning mechanisms described in this report. It is expected that others may copy the tuner and antenna designs and achieve similar results. If new designs are attempted, they may be compared to the results reported here by using the measurement techniques developed here.

It is recommended that MIL-STD-1377 (NAVY) be revised to include provisions for the use of improved antenna designs and field tuners such as those described here. Likewise, automated test techniques based upon taking large data samples should be permitted.

The use of a half-wave dipole equation to describe peak pickup on unshielded wires over the frequency range of 0.1 to 10 GHz appears justified within reasonable engineering tolerances.

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Appendix A

WHEELER'S FORMULAE FOR MICROSTRIP CALCULATIONS

The germain equations from Wheeler (Reference 4) are:

1) For wide strips:

$$d_k = \frac{\pi}{\sqrt{k}} \quad \frac{R_c}{R}$$

$$\frac{w}{h} = \frac{1}{\pi}(d_k - 1) - \frac{1}{\pi}\ln(2 d_k - 1) + \frac{k - 1}{2\pi k}\left[\ln(d_k - 1) + 0.293 - \frac{0.517}{k}\right]$$

2) For narrow strips:

$$h' = h_a + \frac{1}{2}\,\frac{k - 1}{k + 1}\,(0.226 + 0.120/k)$$

$$\frac{h}{w} = \frac{1}{4}\exp(h') - \frac{1}{2}\exp(-h')$$

$d_k \approx g'$ = effective half width of strip, including flux on both outer and inner faces.

k = dielectric constant of sheet material separating the pair of strips.

R_c = 377 ohm = wave resistance of square area of free space.

R = wave resistance of symmetrical pair of strips on dielectric sheet k; or of one quadrant of its cross section.

w = width of microstrip metal.

h = height of dielectric between metal strips.

$h' = \frac{\pi^2}{g'}$ = separation parameter

h_a = parameter h' for same R but all space filled with average dielectric k_a

$k_a = (\frac{k + 1}{2})$ = average of dielectric constants of sheet and free space.

These equations 1) and 2) are for Wheeler's configuration shown in Figure A-1. For the microstrip configuration, the following changes are made to the formulas to

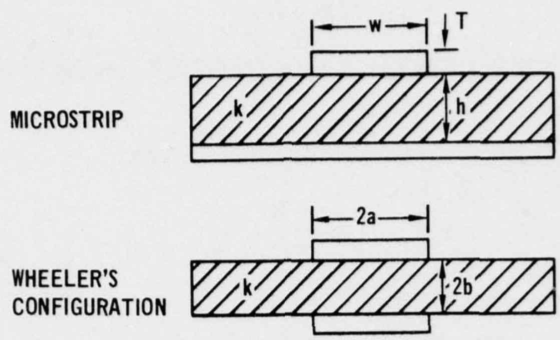


FIGURE A-1 COMPARISON OF WHEELER'S CONFIGURATION AND THE MICROSTRIP CONFIGURATION USED FOR ANTENNA IMPEDANCE MATCHING

compensate for the fact that the microstrip is only half of Wheeler's configuration with a ground plane: (See Reference 9)

$h = b$

$w = 2a$

$R_m = 1/2\ R_W$ = line impedance of the microstrip.

The equations then become (See Reference 6)

3) For wide strip approximation (within 1% of Z for $d_k > 2\pi$, $R_m < \frac{30\pi}{\sqrt{k}}$)

$$d_k = \frac{60\pi^2}{\sqrt{k}\ R_m}$$

$$w/h = 2\left[\frac{d_k - 1}{\pi} - \frac{\ln (2\,dk - 1)}{\pi} + \frac{k - 1}{2\pi k}\{\ln (d_k - 1) + 0.293 - \frac{0.517}{k}\}\right]$$

4) For narrow strip approximation (.5% of R for W/h <2, or h' > 1.485)

$$h' = \sqrt{\frac{\frac{k + 1}{2}\ R_m}{60}} = + \frac{k - 1}{k + 1}(0.226 + 0.120/k)$$

$$w/h = \frac{8}{e^{h'} - 2e^{-h'}}$$

Thickness compensation (also from Wheeler):

ΔW is subtracted from calculated w

If $w/h < 1/(2\pi)$ and $T < w/2$, then $\Delta w = T/k\pi\ (\ln \frac{4\pi w}{T} + 1)$

If $w/h > 1/(2\pi)$ and $T < h/\pi 4$, then $\Delta w = T/k\pi\ (\ln (\frac{2h}{T}) + 1)$

where

T = thickness of microstrip metal (See Figure A-1).

Appendix B contains the computer program used to calculate the microstrip widths, followed with the results.

Appendix B

Microstrip Width Calculations Computer Program

```
10 PRINT
20 PRINT "MICROSTRIP IMPEDANCE TRANSFORMER CALCULATIONS"
30 PRINT
40 DISP "LOWER IMPEDANCE IS ";
50 INPUT Z1
60 DISP "HIGHER IMPEDANCE IS ";
70 INPUT Z2
80 PRINT "TRANSITION FROM";Z1;"TO";Z2;"OHMS"
90 PRINT
100 DISP "DIELECTRIC CONSTANT IS ";
110 INPUT E
120 DISP "HEIGHT OF DIELECTRIC IS ";
130 INPUT H
140 PRINT E;"DIELECTRIC CONSTANT MATRIAL OF HEIGHT";H
150 PRINT
160 DISP "LENGTH OF CONDUCTOR IS ";
170 INPUT L
180 DISP "THICKNESS OF CONDUCTOR IS ";
190 INPUT T
200 PRINT "CONDUCTOR";L;"LONG AND";T;"THICK"
210 PRINT
220 DISP "INCREMENT FOR OUTPUT IS ";
230 INPUT I
240 L1=L*SQR(E)
250 PRINT "ELECTRICAL LENGTH IS";L1
260 PRINT
270 F=(2165*LGT(Z2/Z1))/L1
280 PRINT "CUTOFF FREQUENCY IS";F;"MHZ"
290 PRINT
300 PRINT "LENGTH","ELEC LENGTH","IMP","WIDTH","CORR WIDTH"
310 PRINT
320 R=LOG(Z2/Z1)
330 FOR L2=0 TO L STEP I
340 Z=Z1*EXP((R*L2)/L)
350 L1=L2*SQR(E)
360 D=(PI*PI*60)/(SQR(E)*Z)
370 W1=(D-1)/PI-LOG(2*D-1)/PI
380 W1=W1+(E-1)*(LOG(D-1)+0.293-0.517/E)/(2*PI*E)
390 W1=W1*2
400 H1=(SQR((E+1)/2)*Z)/60+((E-1)*(0.226+0.12/E))/(E+1)
410 W2=8/(EXP(H1)-2*EXP(-H1))
420 IF W2<2 THEN 470
430 IF W1>4 THEN 490
440 P=(W1-2)/2
450 W=W1*P+W2*(1-P)
460 GOTO 500
470 W=W2
480 GOTO 500
```

```
490 W=W1
500 IF W>1/(2*PI) THEN 570
510 W=W*H
520 IF T<W/2 THEN 550
530 W3=9999
540 GOTO 620
550 W3=W-(T*(LOG((4*PI*W)/T)+1))/(E*PI)
560 GOTO 620
570 W=W*H
580 IF T>H/(4*PI) THEN 610
590 W3=9999
600 GOTO 620
610 W3=W-(T*(LOG((2*H)/T)+1))/(E*PI)
620 PRINT L2,L1,Z,W,W3
630 NEXT L2
640 PRINT
650 PRINT
660 PRINT
670 PRINT
680 END
```

```
MICROSTRIP IMPEDANCE TRANSFORMER CALCULATIONS

TRANSITION FROM 50    TO 108.27   OHMS

 2.5  DIELECTRIC CONSTANT MATRIAL OF HEIGHT 0.125

CONDUCTOR 6.56    LONG AND 1.40000E-03   THICK

ELECTRICAL LENGTH IS 10.37227073

CUTOFF FREQUENCY IS 70.03674277   MHZ
```

LENGTH	ELEC LENGTH	IMP	WIDTH	CORR WIDTH
0	0	50	0.355854565	9999
0.1	0.158113883	50.59235724	0.349509778	9999
0.2	0.316227766	51.19173222	0.343246683	9999
0.3	0.474341649	51.79820809	0.337065314	9999
0.4	0.632455532	52.41186896	0.330965588	9999
0.5	0.790569415	53.03279997	0.324947314	9999
0.6	0.948683298	53.66109723	0.319010205	9999
0.7	1.106797181	54.29681790	0.313153886	9999
0.8	1.264911064	54.94008017	0.307377904	9999
0.9	1.423024947	55.59096325	0.301681737	9999
1	1.58113883	56.24955744	0.296064798	9999
1.1	1.739252713	56.91595410	0.290526449	9999
1.2	1.897366596	57.59024565	0.285066000	9999
1.3	2.055480479	58.27252563	0.279682723	9999
1.4	2.213594362	58.96288868	0.274375852	9999
1.5	2.371708245	59.66143056	0.269144594	9999

LENGTH	ELEC LENGTH	IMP	WIDTH	CORR WIDTH
1.6	2.529822128	60.36824817	0.263988128	9999
1.7	2.687936011	61.08343955	0.258905616	9999
1.8	2.846049894	61.8071039	0.253896204	9999
1.9	3.004163777	62.53934162	0.248930786	9999
2	3.16227766	63.28025426	0.244022813	9999
2.1	3.320391543	64.02994459	0.239186126	9999
2.2	3.478505426	64.78851662	0.234419541	9999
2.3	3.636619309	65.55607555	0.229721914	9999
2.4	3.794733192	66.33272788	0.225092142	9999
2.5	3.952847075	67.11858131	0.220529161	9999
2.6	4.110960958	67.91374487	0.216031944	9999
2.7	4.269074841	68.71832884	0.211599502	9999
2.8	4.427188724	69.53244483	0.207230880	9999
2.9	4.585302607	70.35620577	0.202925159	9999
3	4.74341649	71.18972593	0.198681451	9999
3.1	4.901530373	72.03312093	0.194498904	9999
3.2	5.059644256	72.88650775	0.190376694	9999
3.3	5.217758139	73.75000476	0.186314030	9999
3.4	5.375872022	74.62373174	0.182310149	9999
3.5	5.533985905	75.5078099	0.178364318	9999
3.6	5.692099788	76.40236186	0.174475829	9999
3.7	5.850213671	77.3075117	0.170644004	9999
3.8	6.008327554	78.22338500	0.166868187	9999
3.9	6.166441437	79.15010877	0.163147752	9999
4	6.32455532	80.08781157	0.159482091	9999
4.1	6.482669203	81.03662347	0.155870624	9999
4.2	6.640783086	81.99667609	0.152312791	9999
4.3	6.798896969	82.96810259	0.148808053	9999
4.4	6.957010852	83.95103771	0.145355892	9999
4.5	7.115124735	84.94561781	0.14195581	9999
4.6	7.273238618	85.95198085	0.138607327	9999
4.7	7.431352501	86.97026641	0.135309981	9999
4.8	7.589466384	88.00061576	0.132063328	9999
4.9	7.747580267	89.04317180	0.128866939	9999
5	7.90569415	90.09807915	0.125720400	9999
5.1	8.063808033	91.16548414	0.122623313	9999
5.2	8.221921916	92.24553483	0.119575293	9999
5.3	8.380035799	93.33838105	0.116575966	9999
5.4	8.538149682	94.44417437	0.113624973	9999
5.5	8.696263565	95.56306818	0.110721964	9999
5.6	8.854377448	96.69521769	0.107866601	9999
5.7	9.012491331	97.84077993	0.105058553	9999
5.8	9.170605214	98.99991382	0.102297501	9999
5.9	9.328719097	100.1727801	0.099583130	9999
6	9.48683298	101.3595416	0.096915136	9999
6.1	9.644946863	102.5603627	0.094293218	9999
6.2	9.803060746	103.7754102	0.091717083	9999
6.3	9.961174630	105.0048525	0.089186442	9999
6.4	10.11928851	106.2488602	0.086701009	9999
6.5	10.27740240	107.5076059	0.084260502	9999

Appendix C

MINIMUM TRANSMISSION LOSS PLOTS

CONFIGURATION	FIGURE NUMBER
Configurations Tested in Empty EM Chamber	
LBR + SBR, Rotation, Matched	C-1
LBR, Rotation + Translation, Matched	C-2
LBR, Rotation, Matched	C-3
Original, Rotation + Translation, Unmatched	C-4
SBR, Rotation, Matched	C-5
LBR, Rotation, Unmatched	C-6
Large Multi-Surfaced, Rotation, Unmatched	C-7
SBR, Rotation, Unmatched	C-8, C-9
Large Circular, Translation, Unmatched	C-10
Curved "S", Rotation, Unmatched	C-11, C-12
Slanted Rectangle, Rotation, Unmatched	C-13, C-14
Single-Bladed Fan, Rotation, Unmatched	C-15, C-16
Original, Rotation, Unmatched	C-17, C-18
Original, Translation, Unmatched	C-19, C-20
Configurations Tested with Equipment in EM Chamber	
LBR + SBR, Matched	C-21
LBR, Rotation + Translation, Matched	C-22
LBR, Rotation, Matched	C-23, C-24
SBR, Rotation, Matched	C-25, C-26
LRB, Rotation, Unmatched	C-27, C-28

LBR - LARGE BENT RECTANGLE

SBR - SMALL BENT RECTANGLE

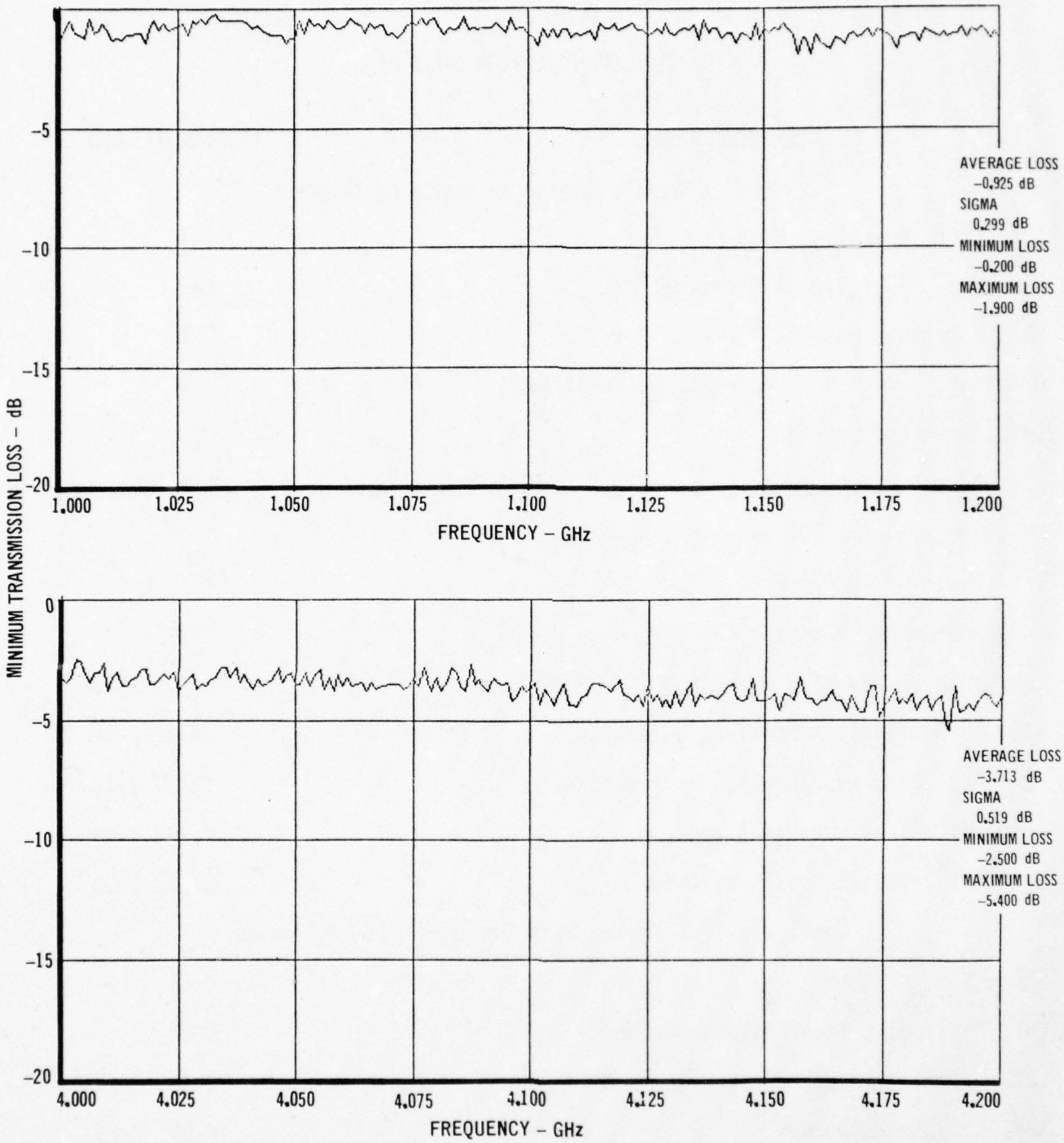


FIGURE C–1 MINIMUM TRANSMISSION LOSS, LARGE BENT RECTANGLE AND SMALL BENT RECTANGLE, ROTATION ONLY, MATCHED ANTENNAS, EMPTY CHAMBER

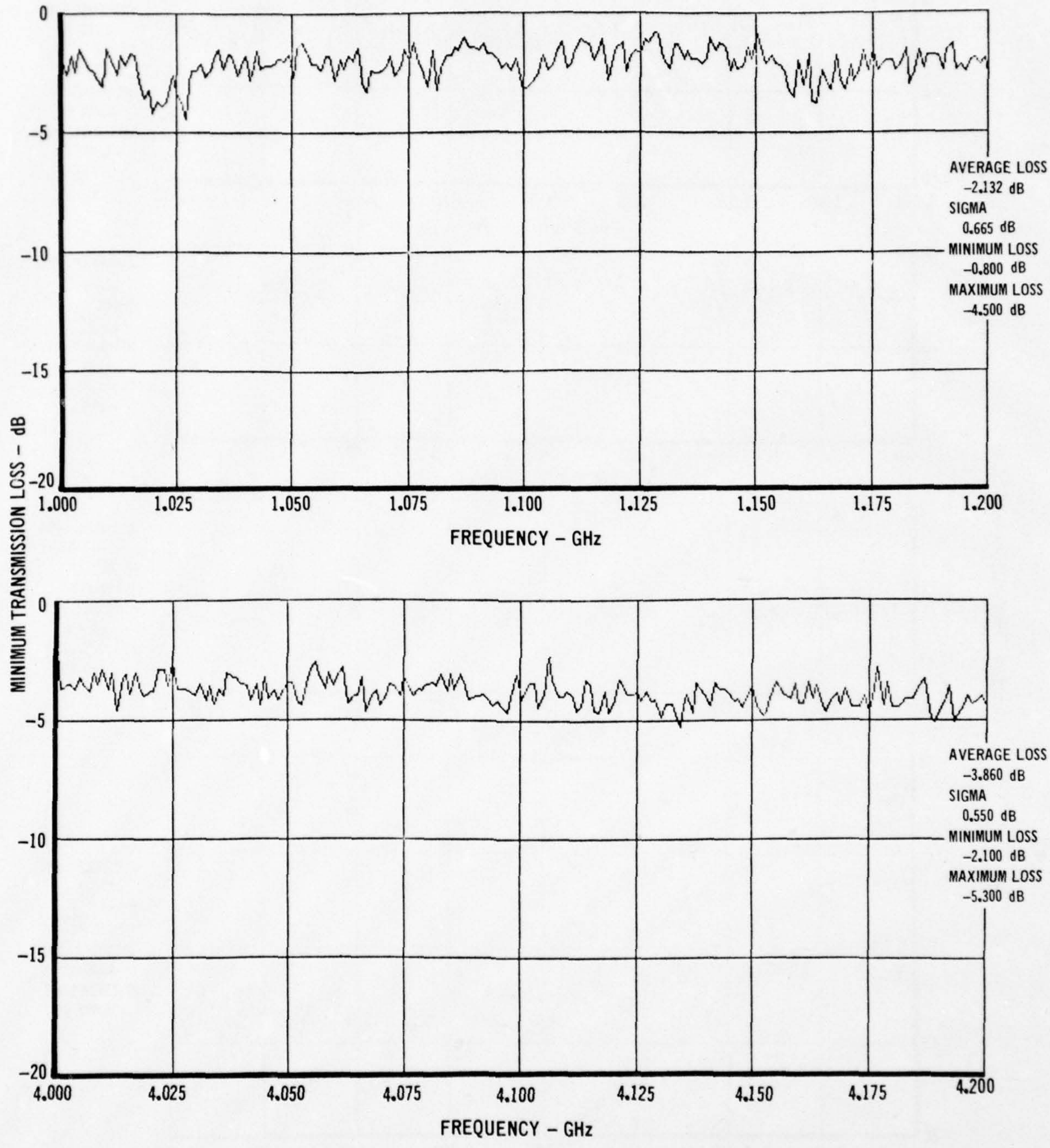


FIGURE C–2 MINIMUM TRANSMISSION LOSS, LARGE BENT RECTANGLE, ROTATION PLUS LONGITUDINAL TRANSLATION, MATCHED ANTENNAS, EMPTY CHAMBER

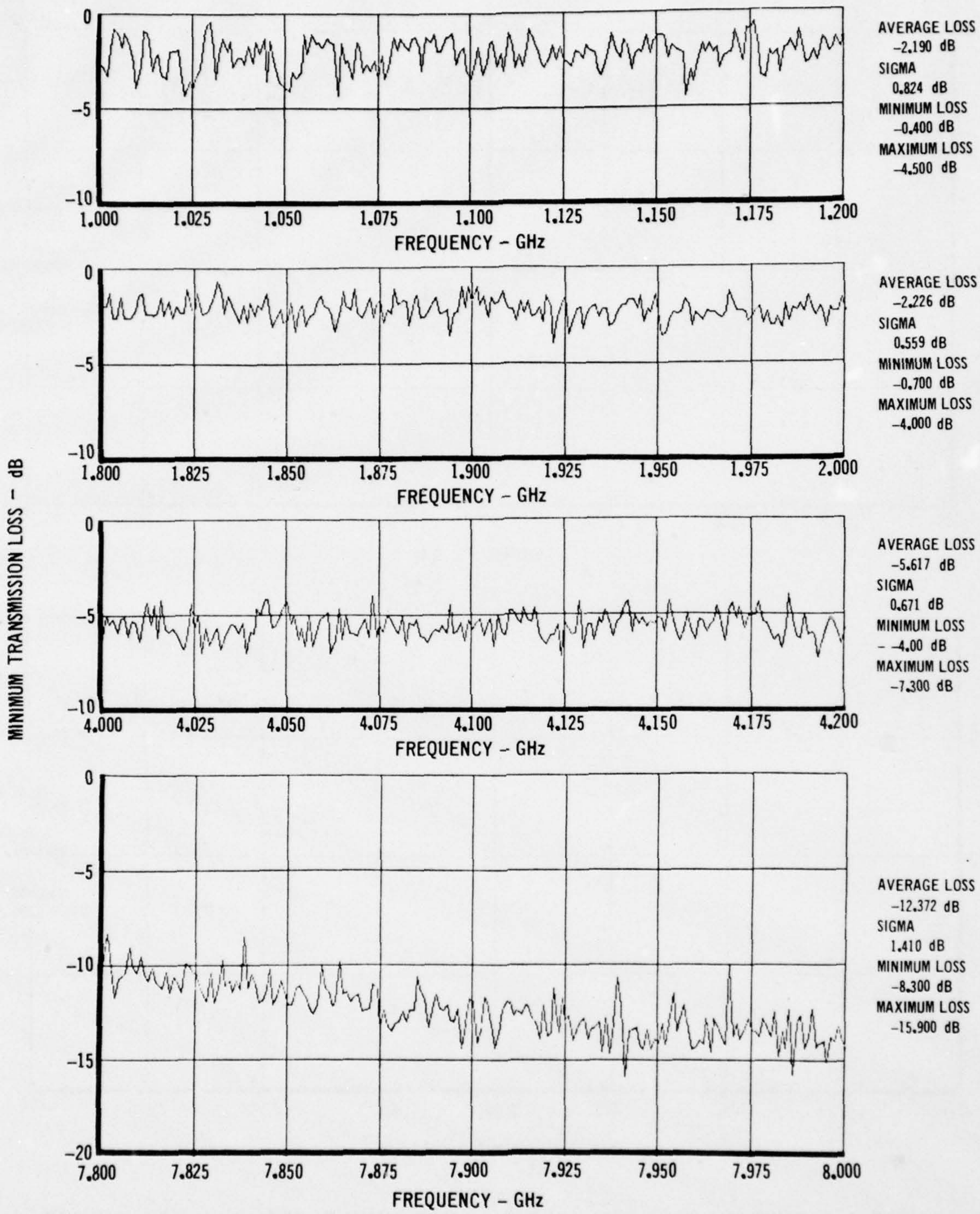


FIGURE C–3 TRANSMISSION LOSS, LARGE BENT RECTANGLE, ROTATION ONLY, MATCHED ANTENNAS, EMPTY CHAMBER

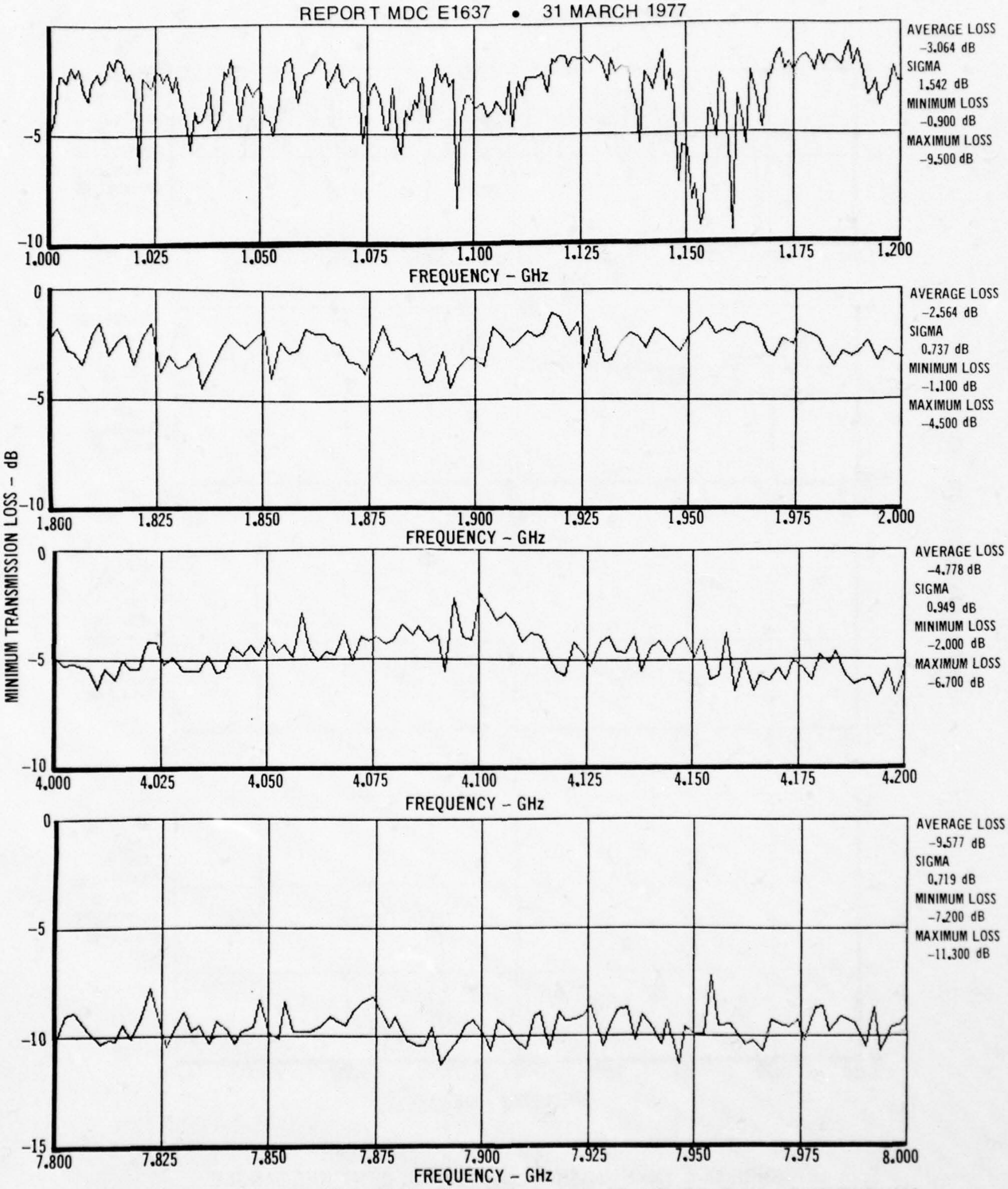


FIGURE C–4 MINIMUM TRANSMISSION LOSS, SMALL STANDARD FAN, LONGITUDINAL TRANSLATION AND ROTATION, UNMATCHED ANTENNAS, EMPTY CHABMER

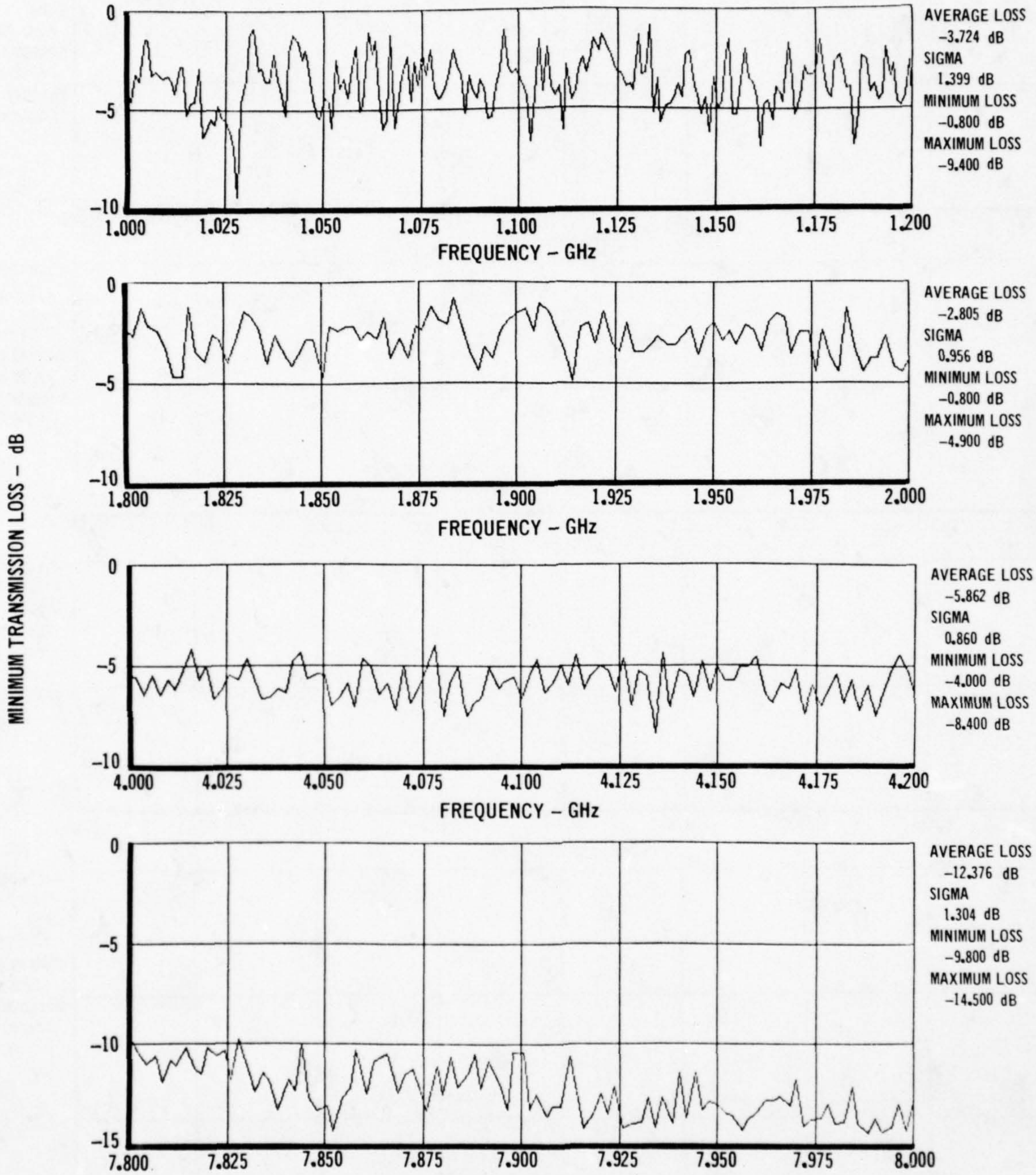


FIGURE C–5 TRANSMISSION LOSS, SMALL BENT RECTANGLE, ROTATION ONLY, MATCHED ANTENNAS, EMPTY CHAMBER

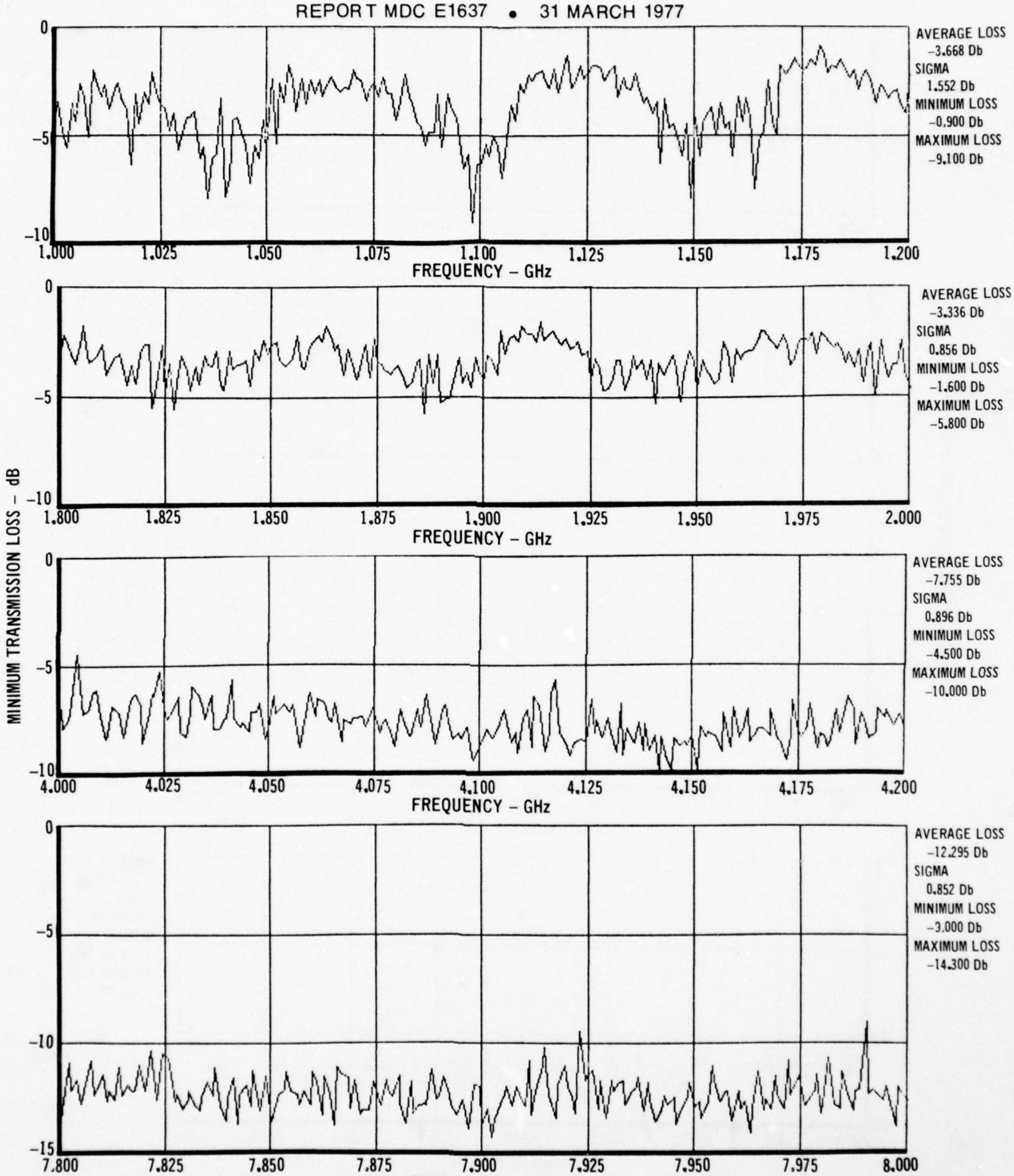


FIGURE C-6 MINIMUM TRANSMISSION LOSS, LARGE BENT RECTANGLE, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

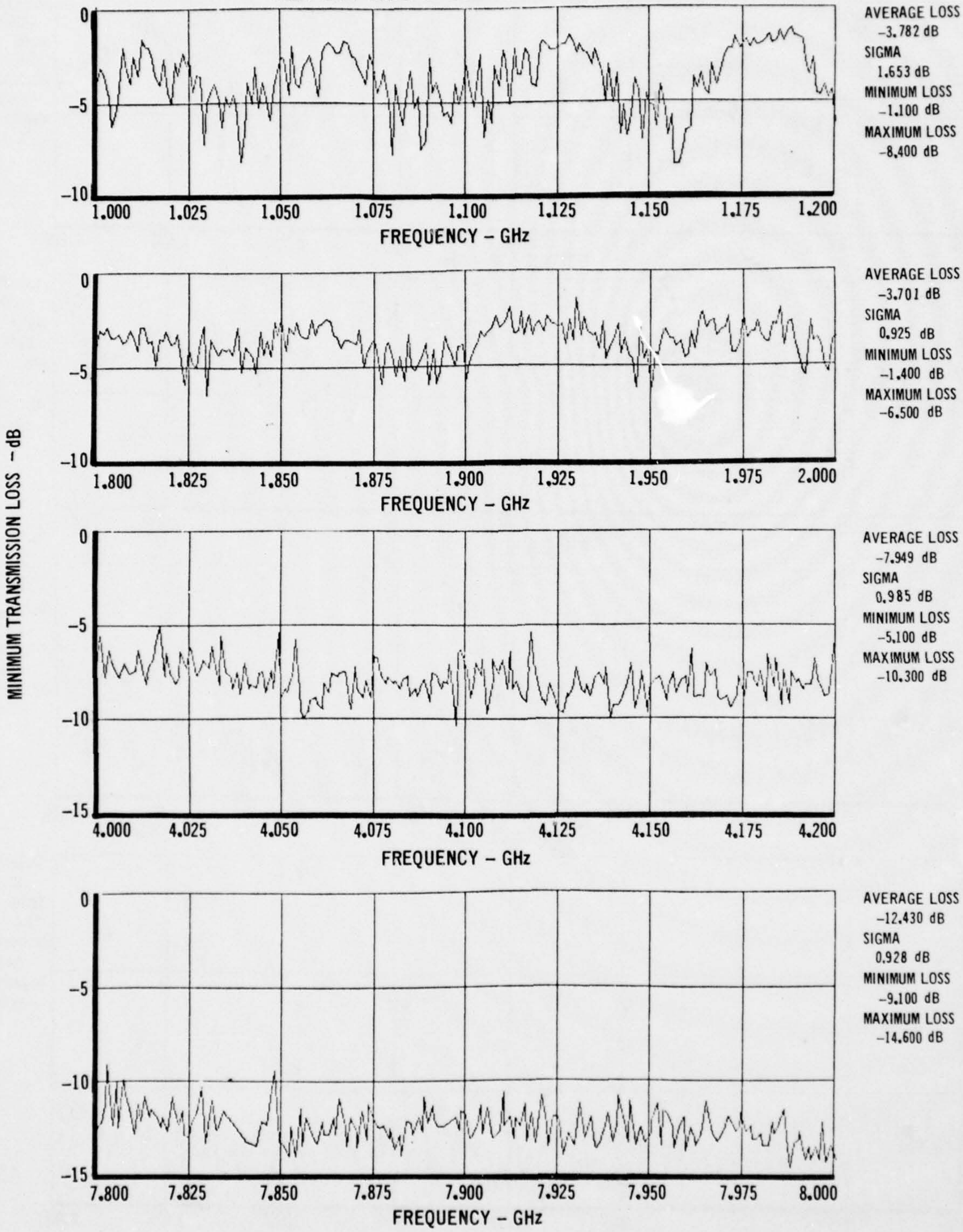


FIGURE C–7 MINIMUM TRANSMISSION LOSS, LARGE MULTI-SURFACED TUNER, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

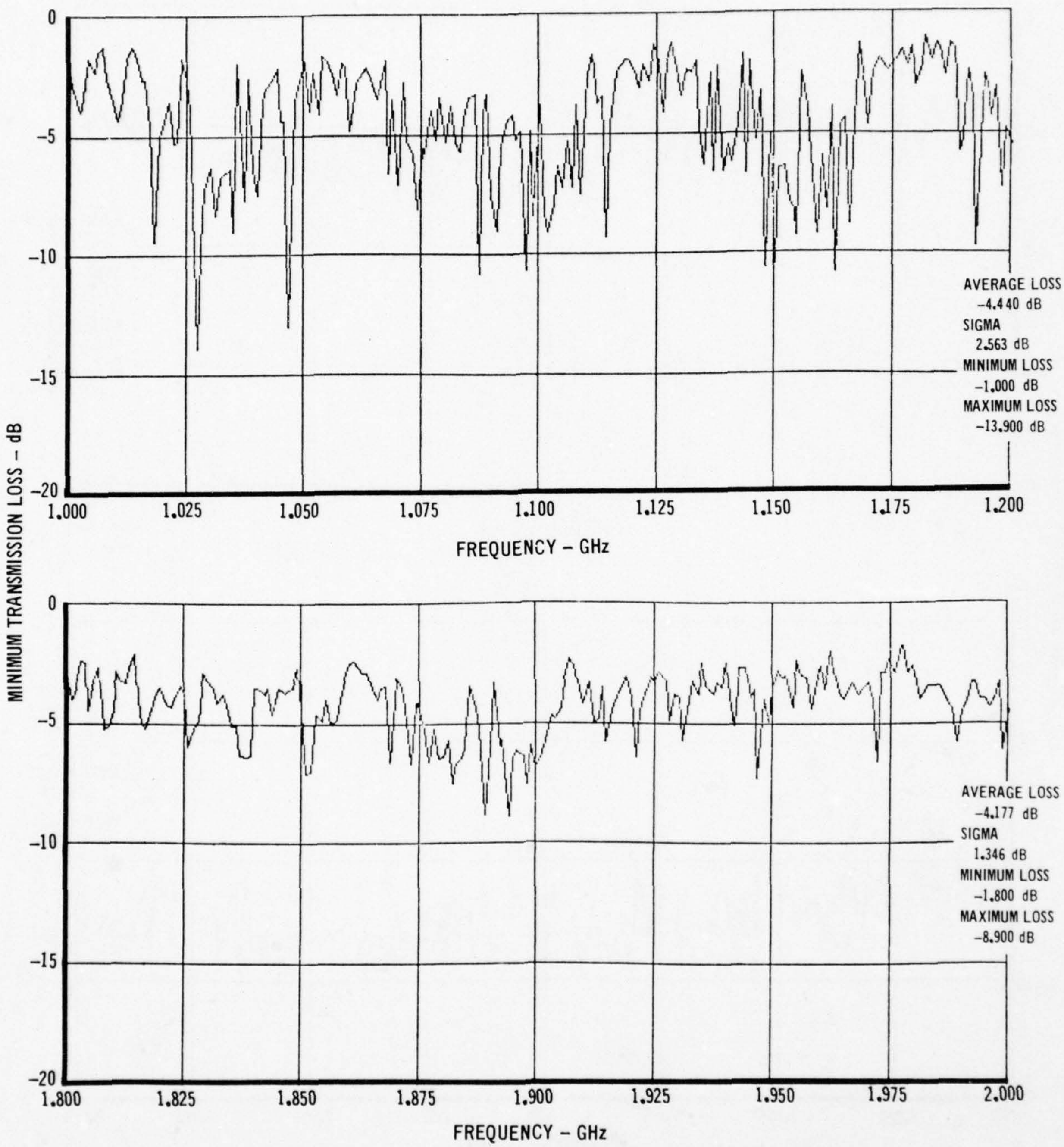


FIGURE C–8 MINIMUM TRANSMISSION LOSS, SMALL BENT RECTANGLE, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

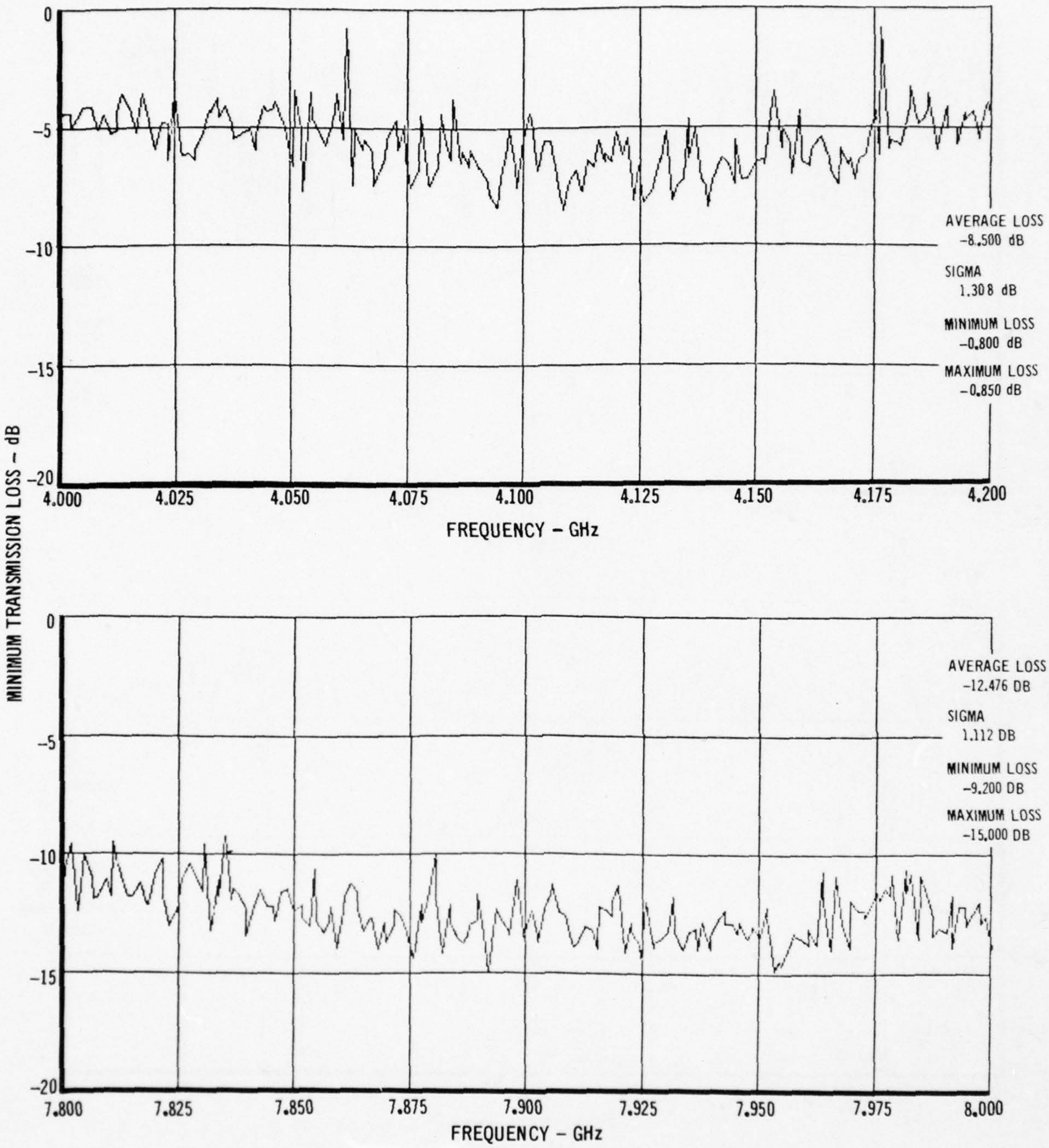


FIGURE C-9 MINIMUM TRANSMISSION LOSS, SMALL BEAT RECTANGLE, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

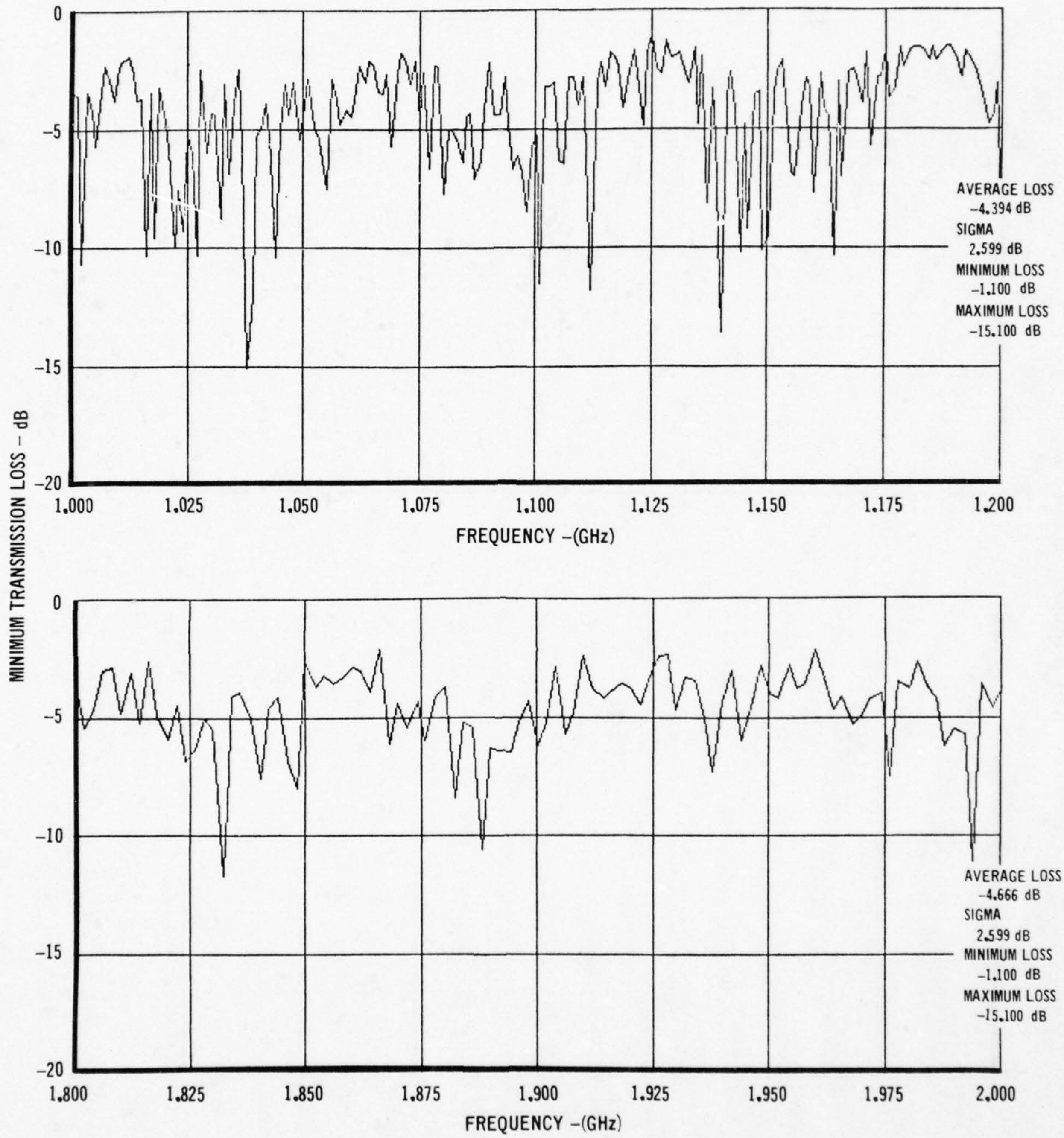


FIGURE C–10 MINIMUM TRANSMISSION LOSS, 30 INCH DIAMETER DISC, LONGITUDINAL TRANSLATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

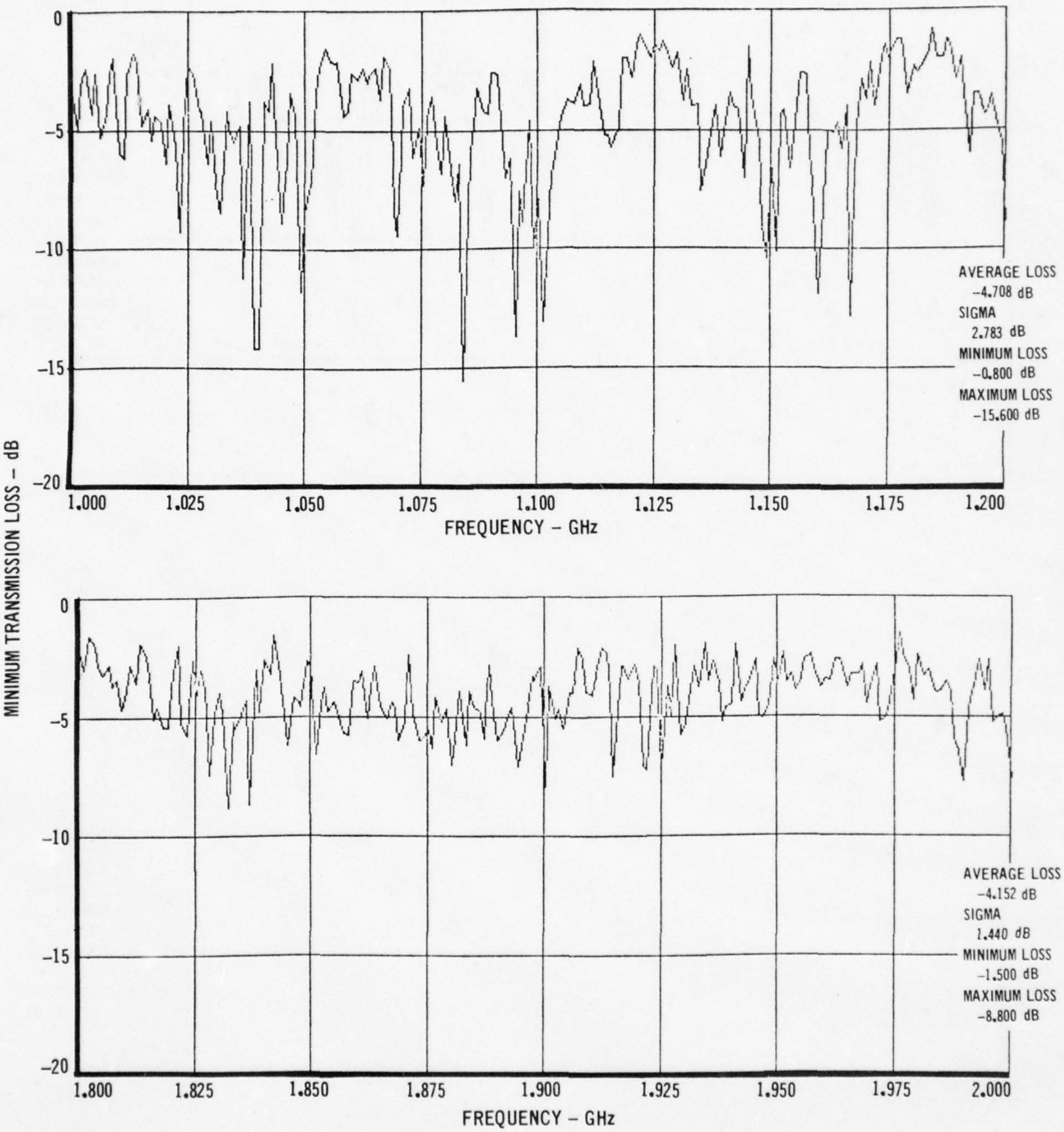


FIGURE C–11 MINIMUM TRANSMISSION LOSS, CURVED "S" TUNER, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

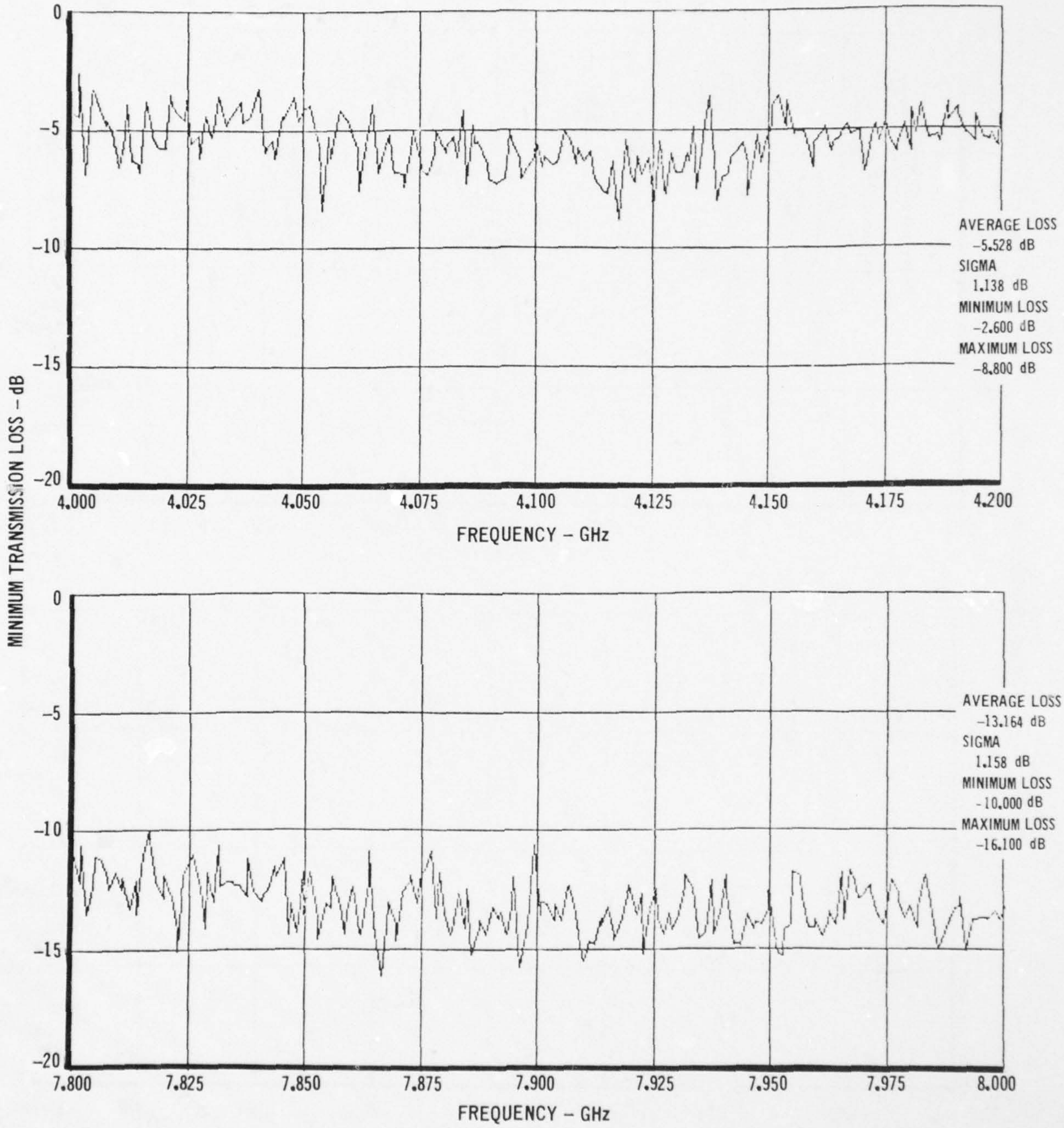


FIGURE C–12 MINIMUM TRANSMISSION LOSS, CURVED "S" TUNER, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

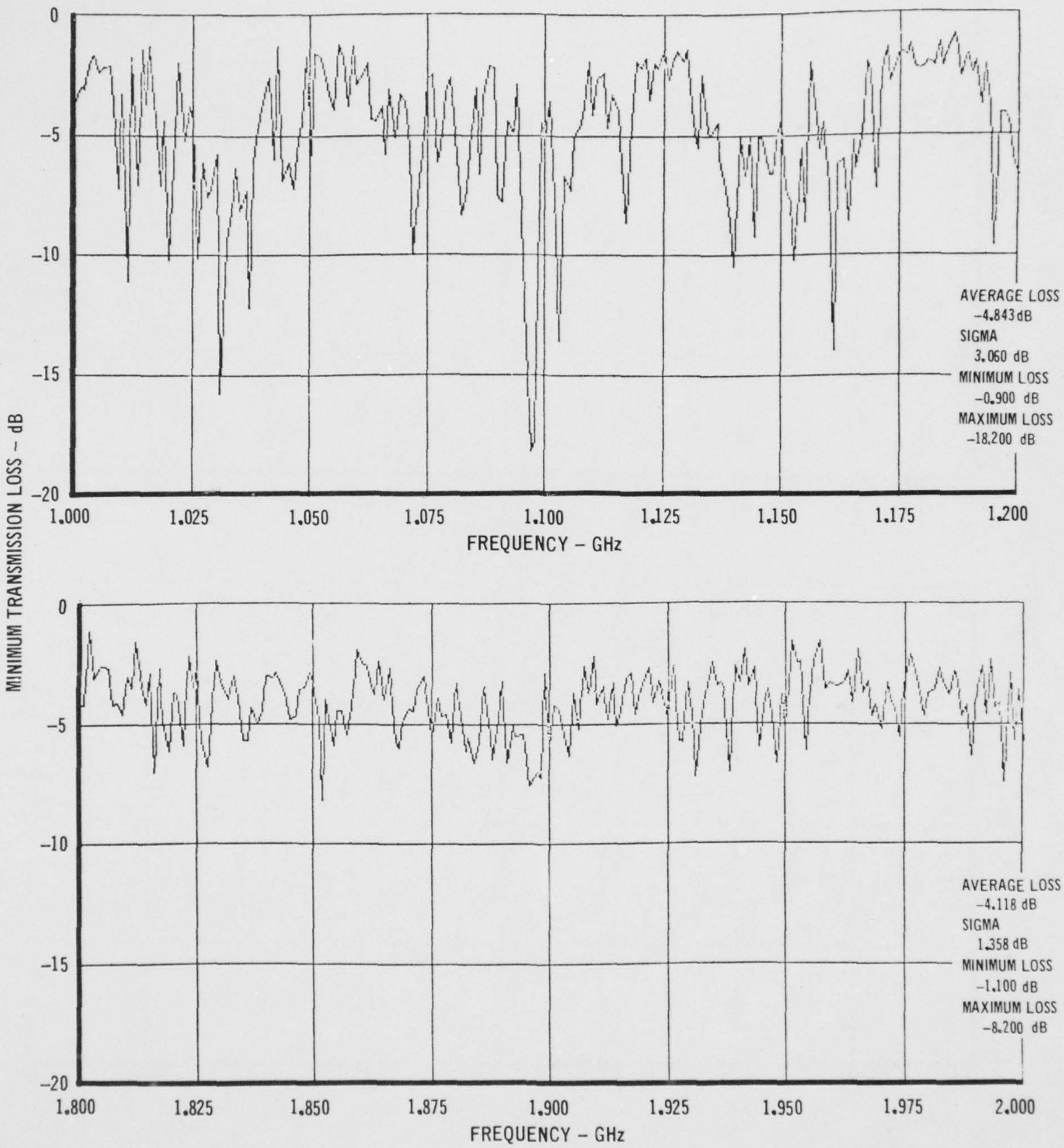


FIGURE C–13 MINIMUM TRANSMISSION LOSS, SLANTED RECTANGLE, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

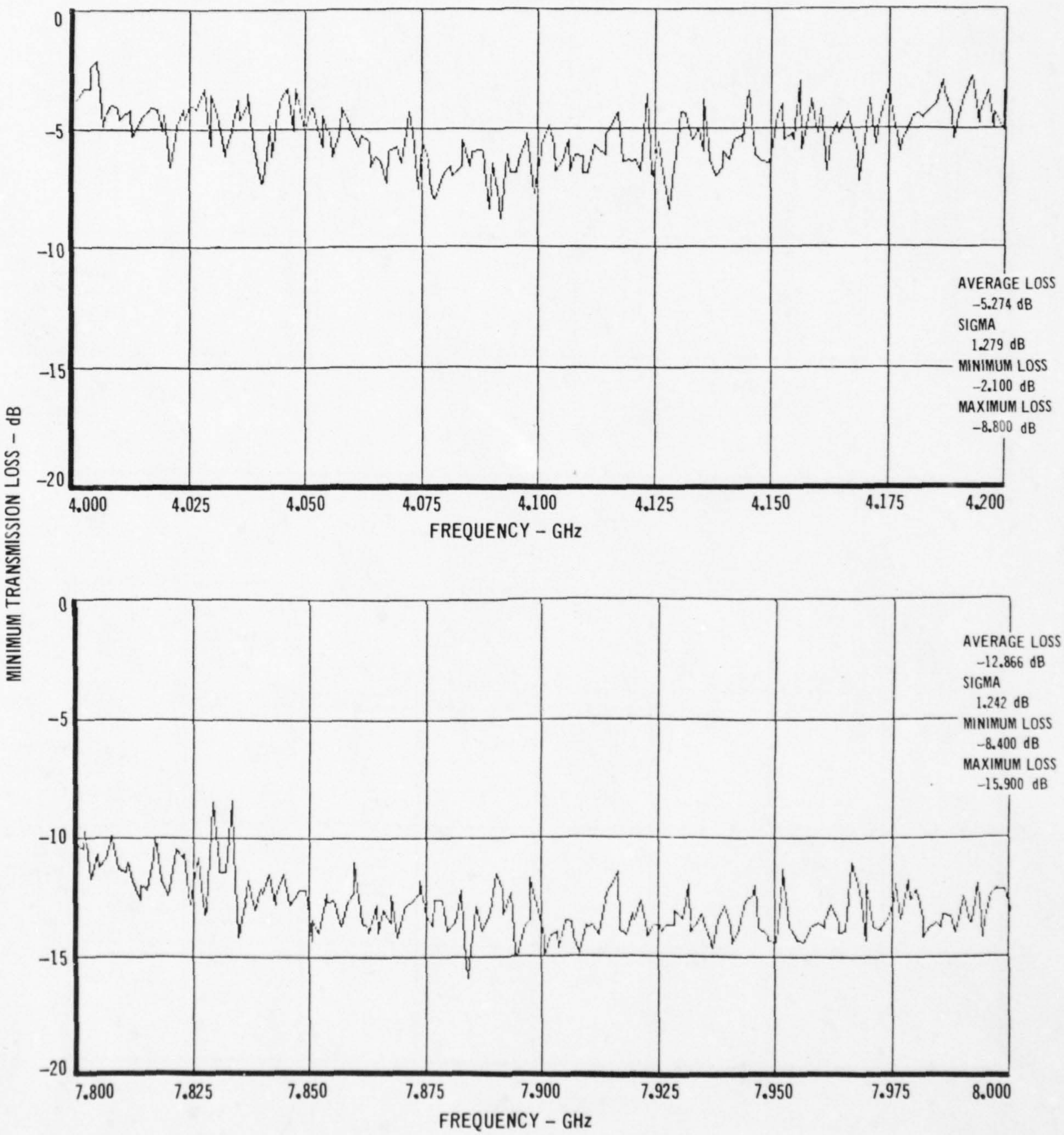


FIGURE C-14 MINIMUM TRANSMISSION LOSS, SLANTED RECTANGLE, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

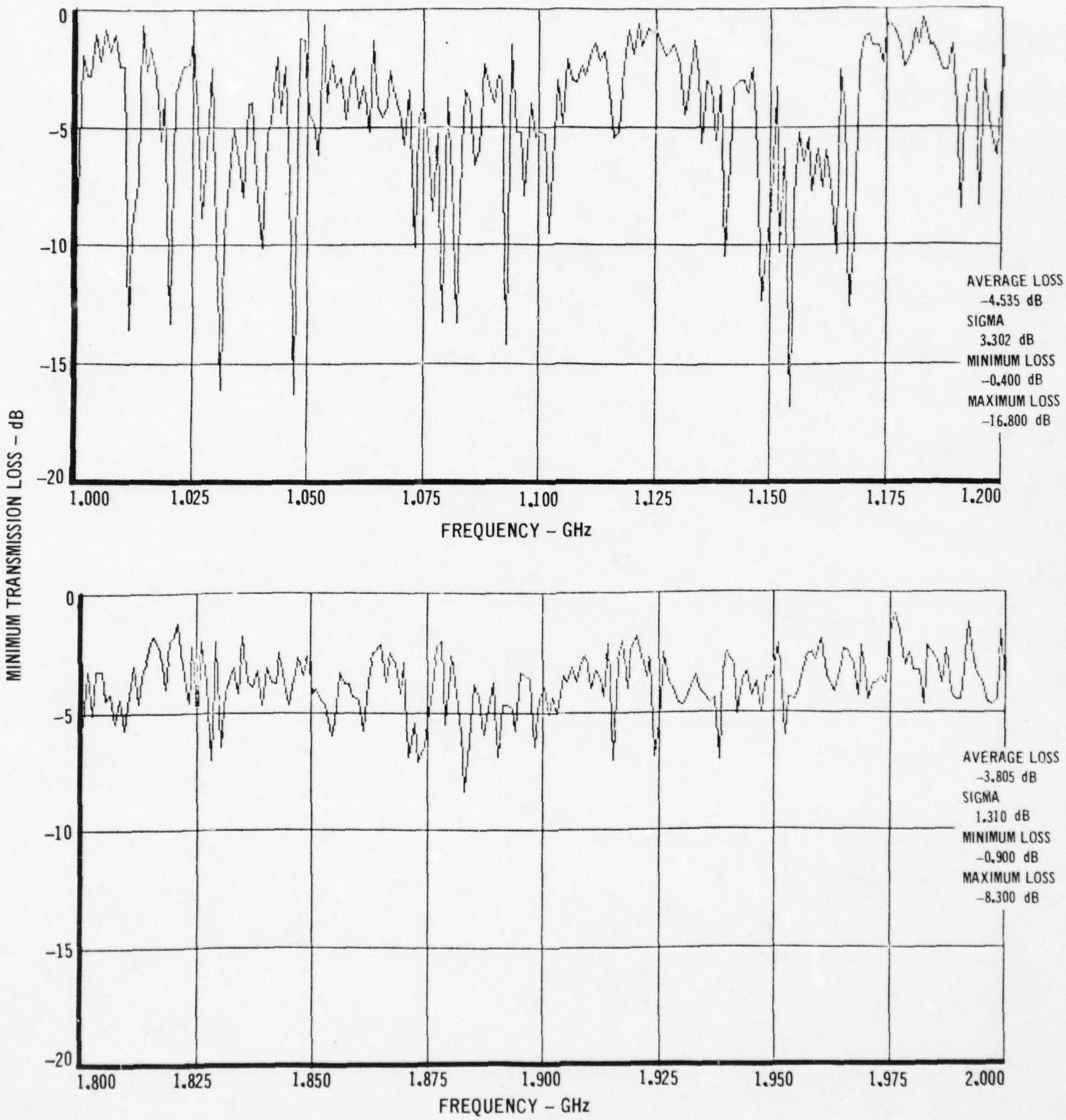


FIGURE C-15 MINIMUM TRANSMISSION LOSS, SINGLE-BLADED TUNER, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

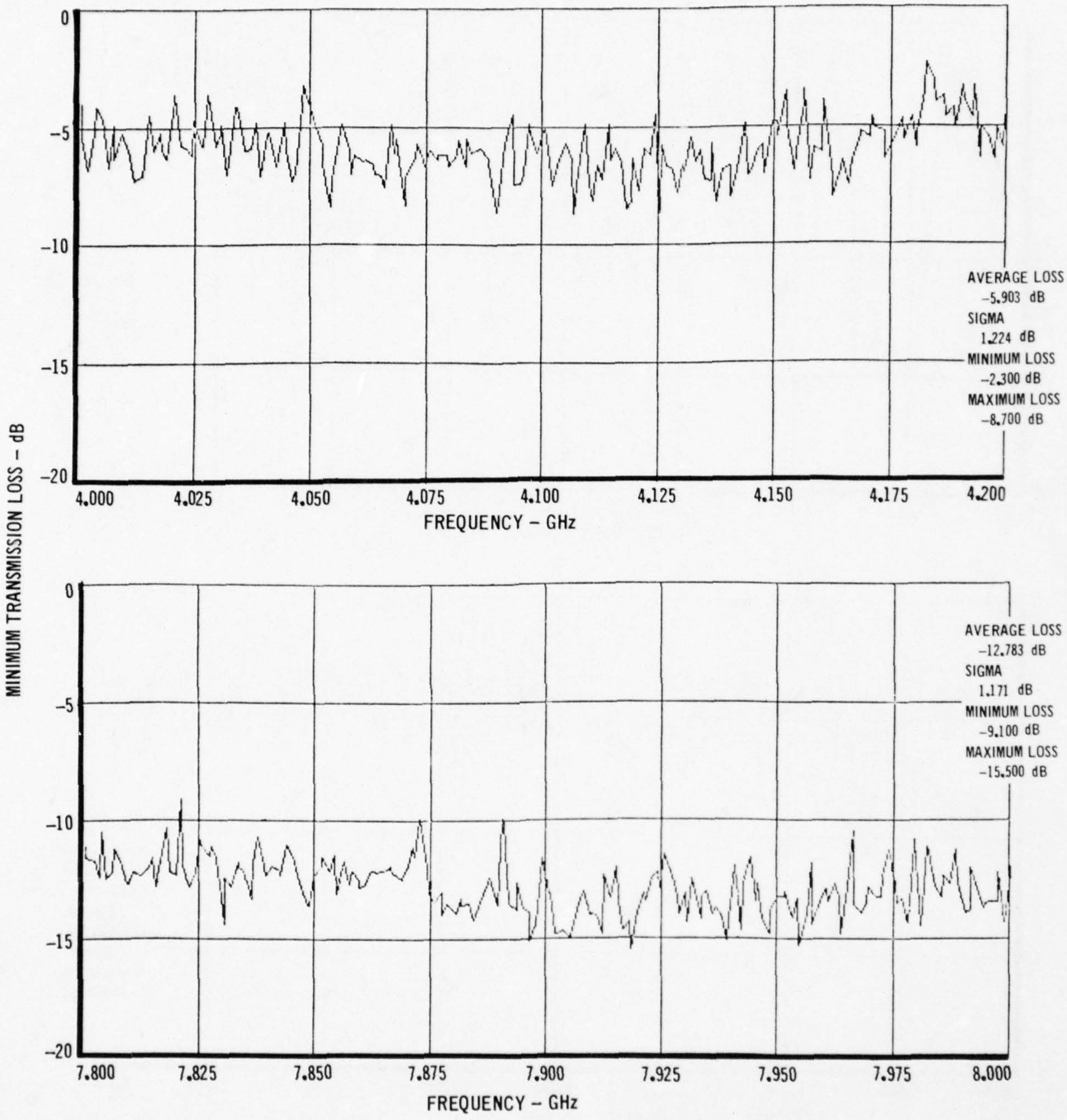


FIGURE C–16 MINIMUM TRANSMISSION LOSS, SINGLE-BLADED TUNER, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

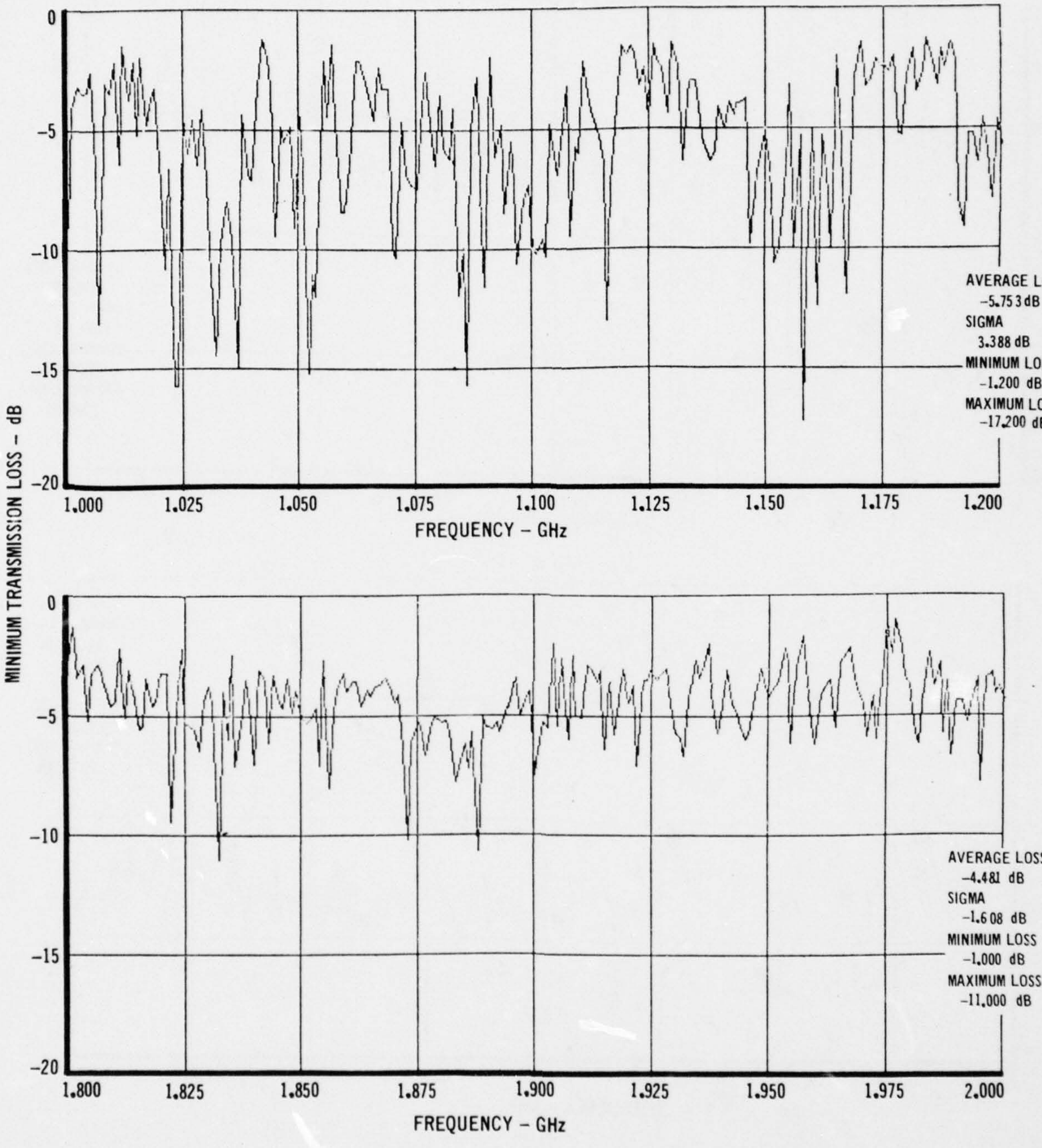


FIGURE C-17 MINIMUM TRANSMISSION LOSS, ORIGINAL FIELD TUNER, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

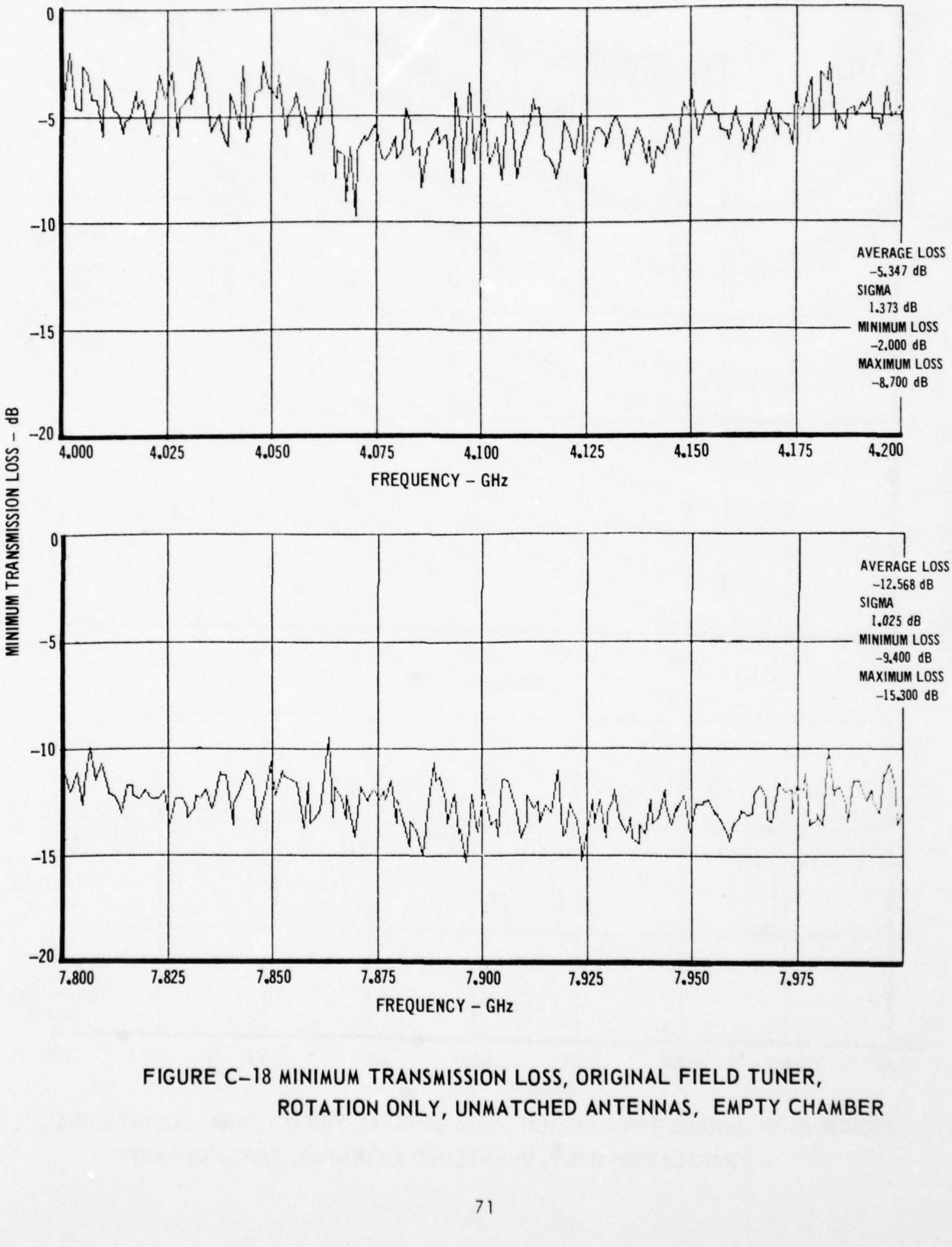
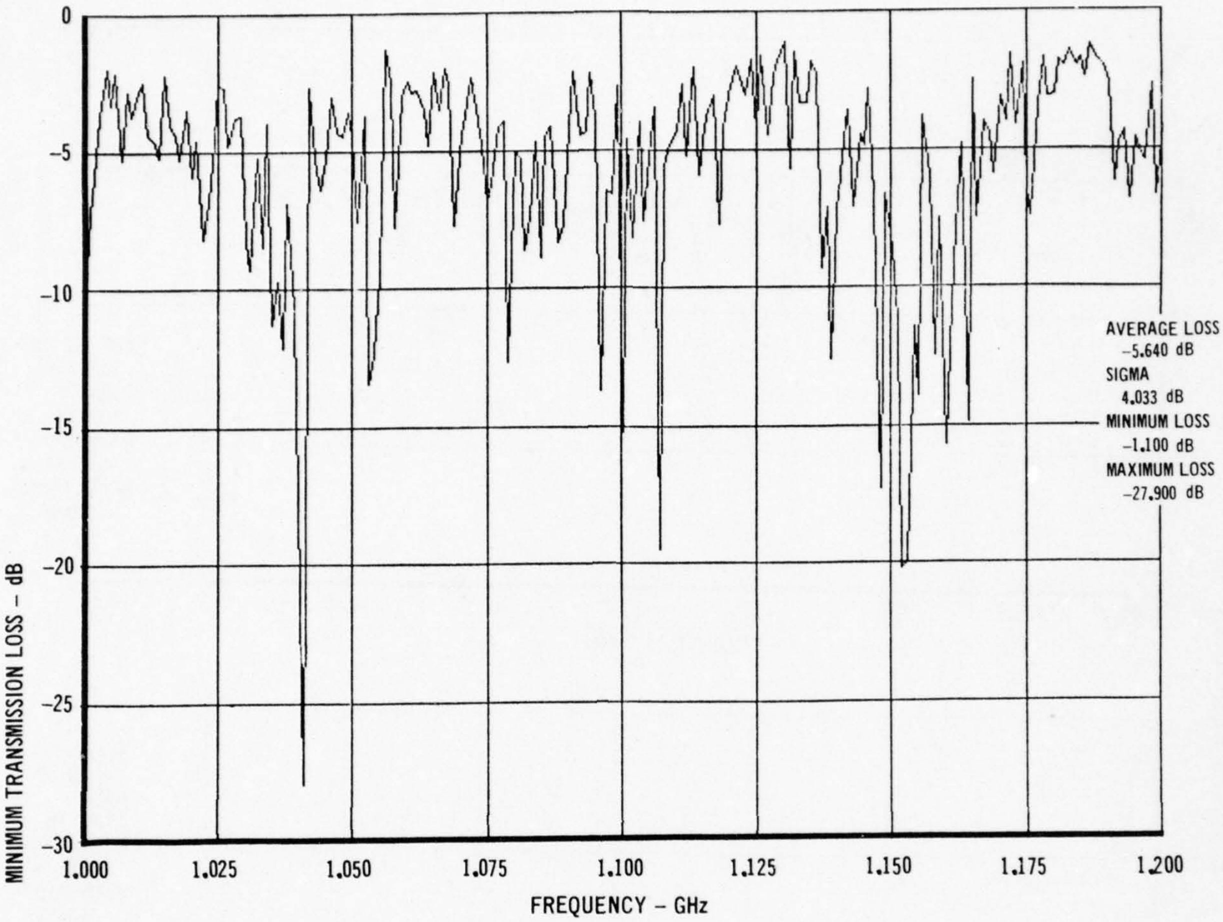


FIGURE C-18 MINIMUM TRANSMISSION LOSS, ORIGINAL FIELD TUNER, ROTATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER



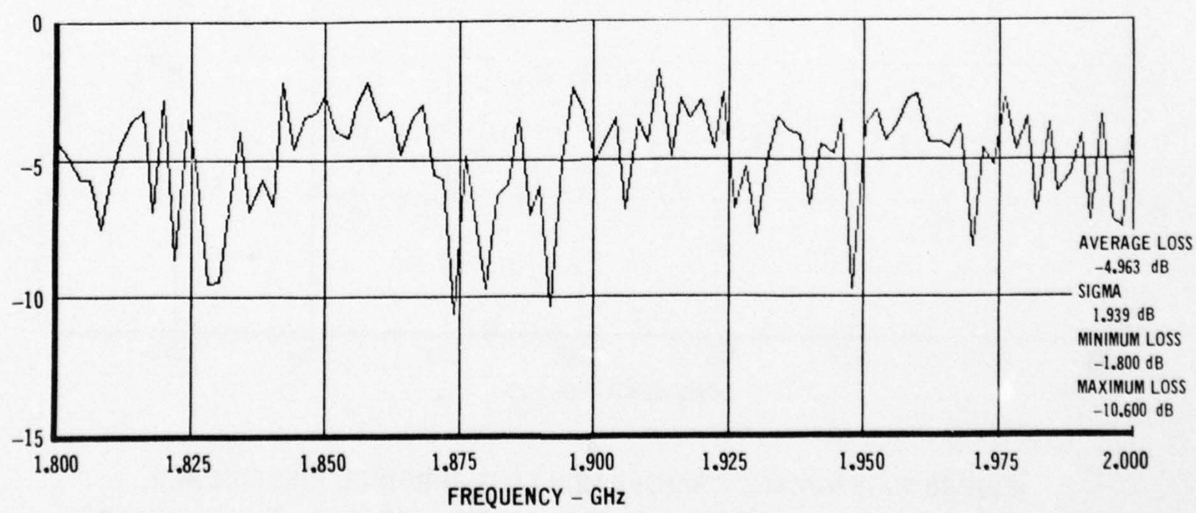


FIGURE C-19 MINIMUM TRANSMISSION LOSS, ORIGINAL FIELD TUNER, LONGITUDINAL TRANSLATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

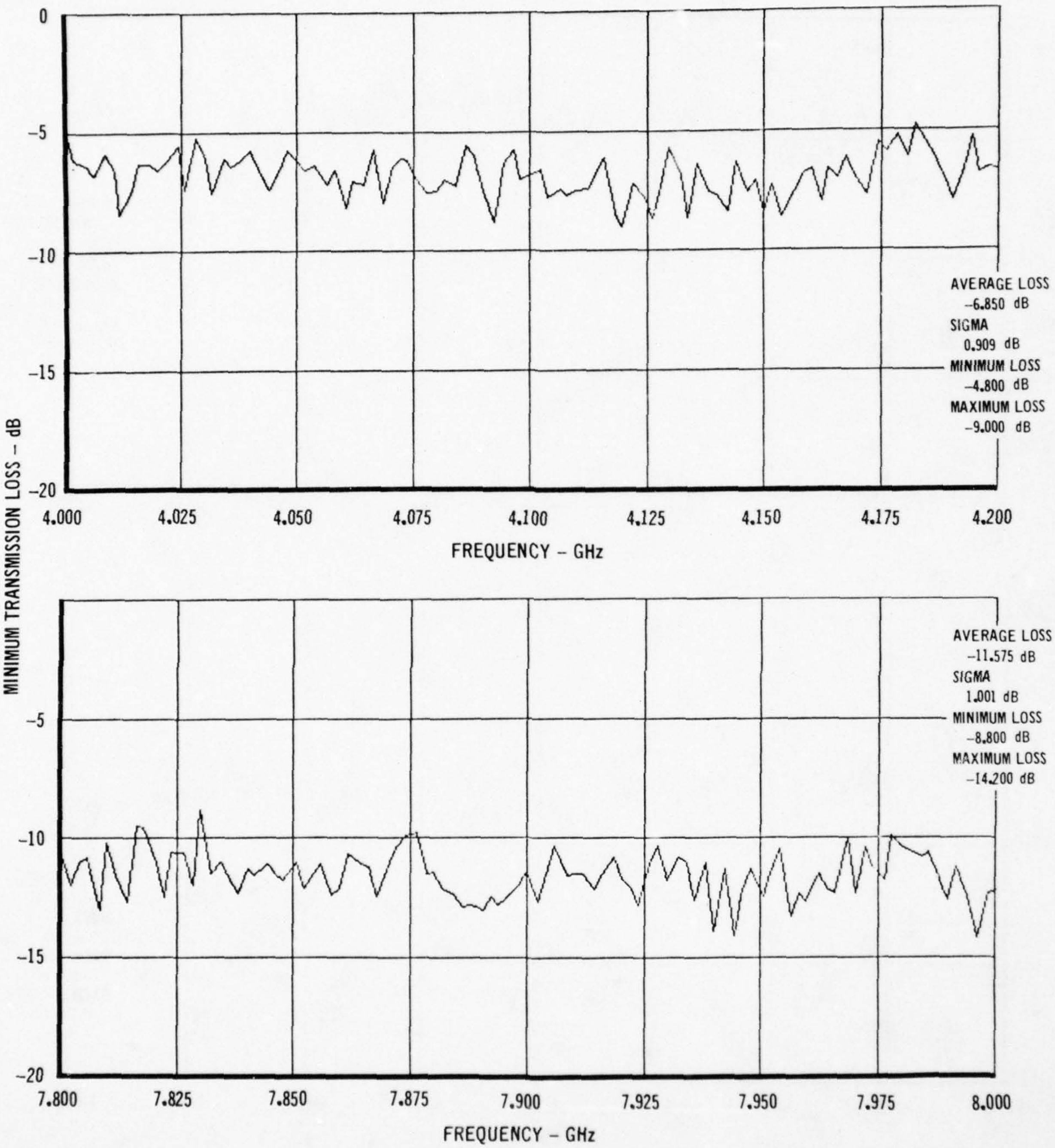


FIGURE C–20 MINIMUM TRANSMISSION LOSS, ORIGINAL FIELD TUNER, LONGITUDINAL TRANSLATION ONLY, UNMATCHED ANTENNAS, EMPTY CHAMBER

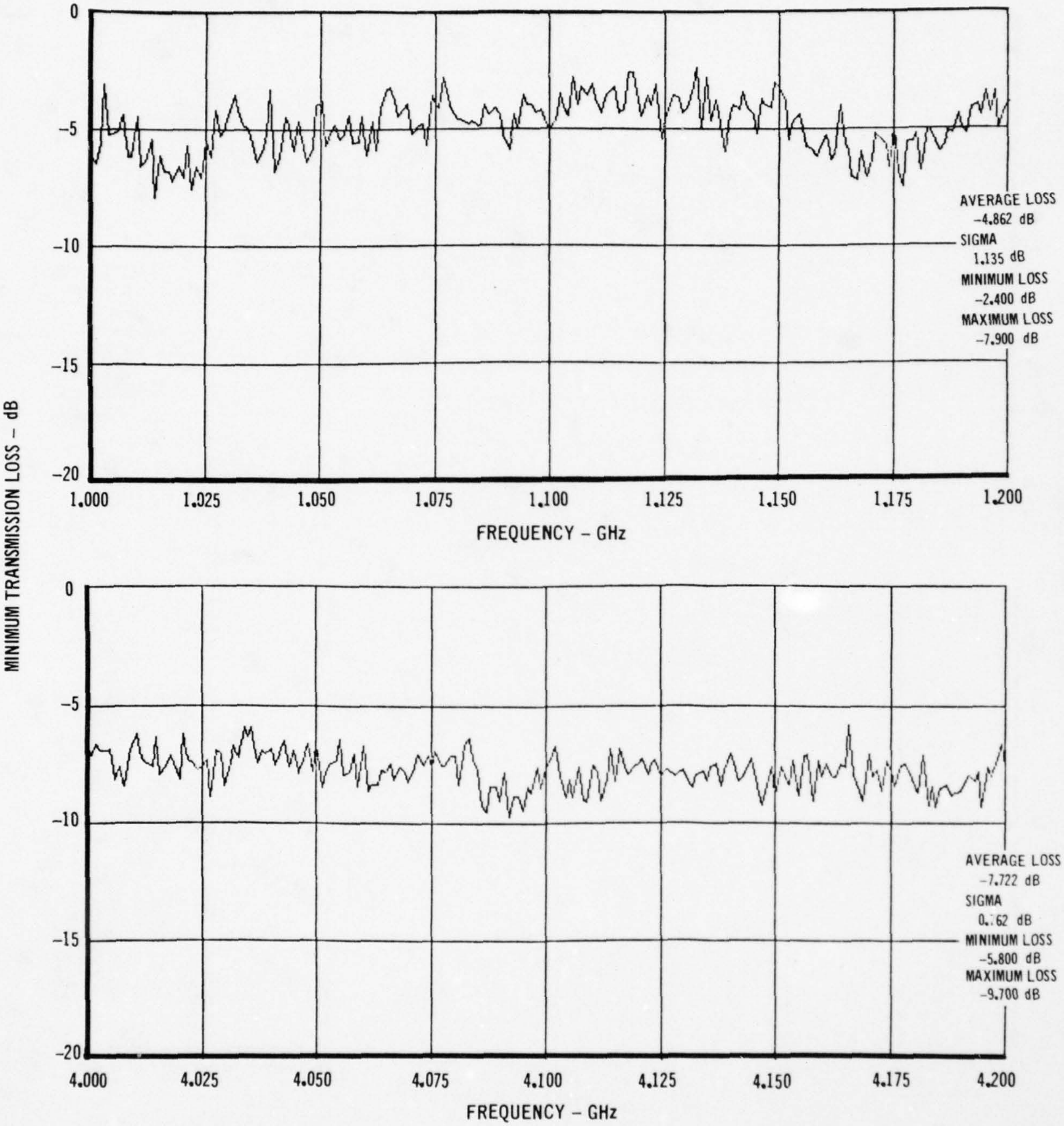


FIGURE C–21 MINIMUM TRANSMISSION LOSS, LARGE BENT RECTANGLE AND SMALL BENT RECTANGLE, ROTATION ONLY, MATCHED ANTENNAS, EQUIPMENT IN CHAMBER

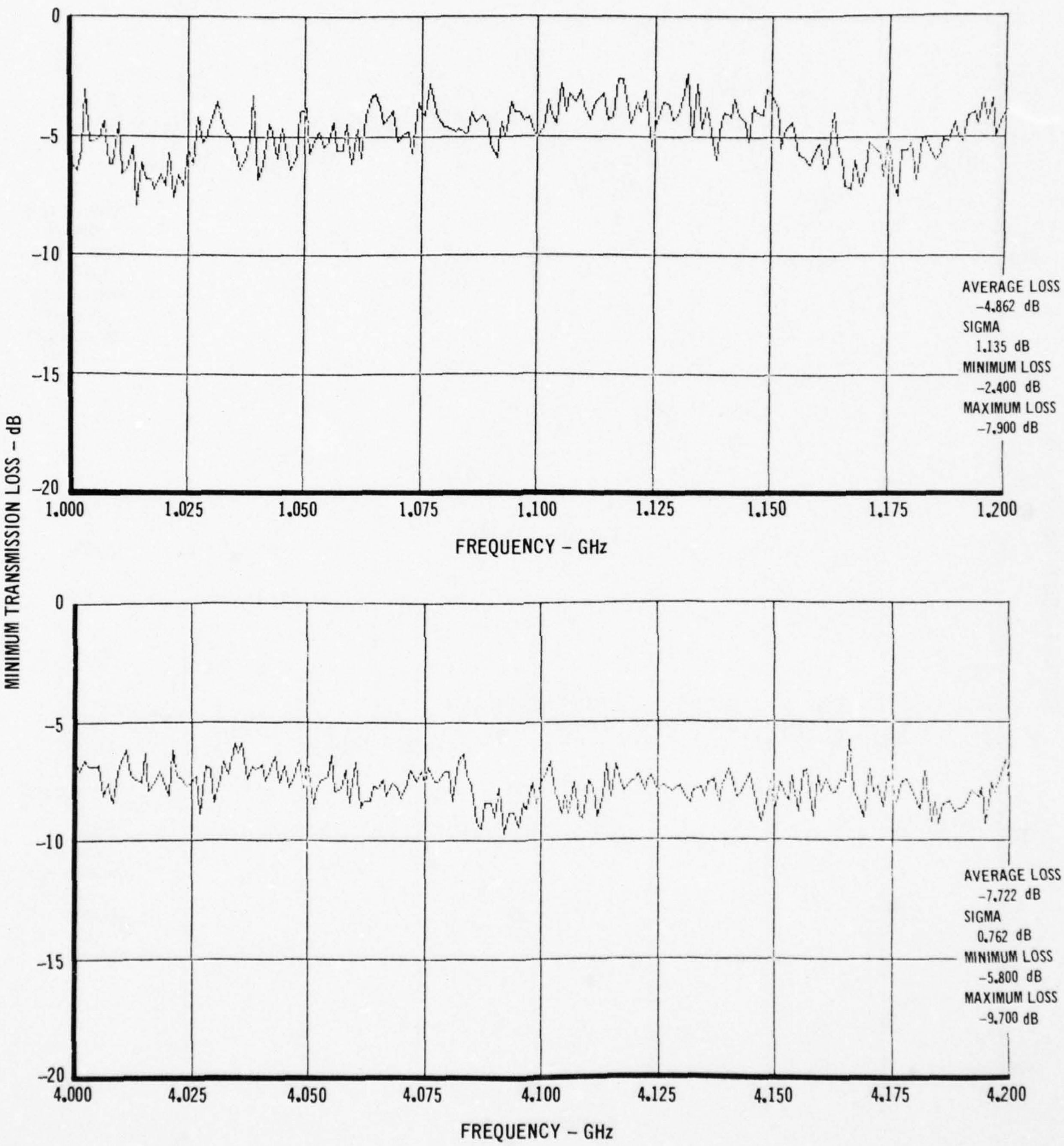


FIGURE C-22 MINIMUM TRANSMISSION LOSS, LARGE BENT RECTANGLE, ROTATION AND TRANSLATION, MATCHED ANTENNAS, EQUIPMENT IN CHAMBER

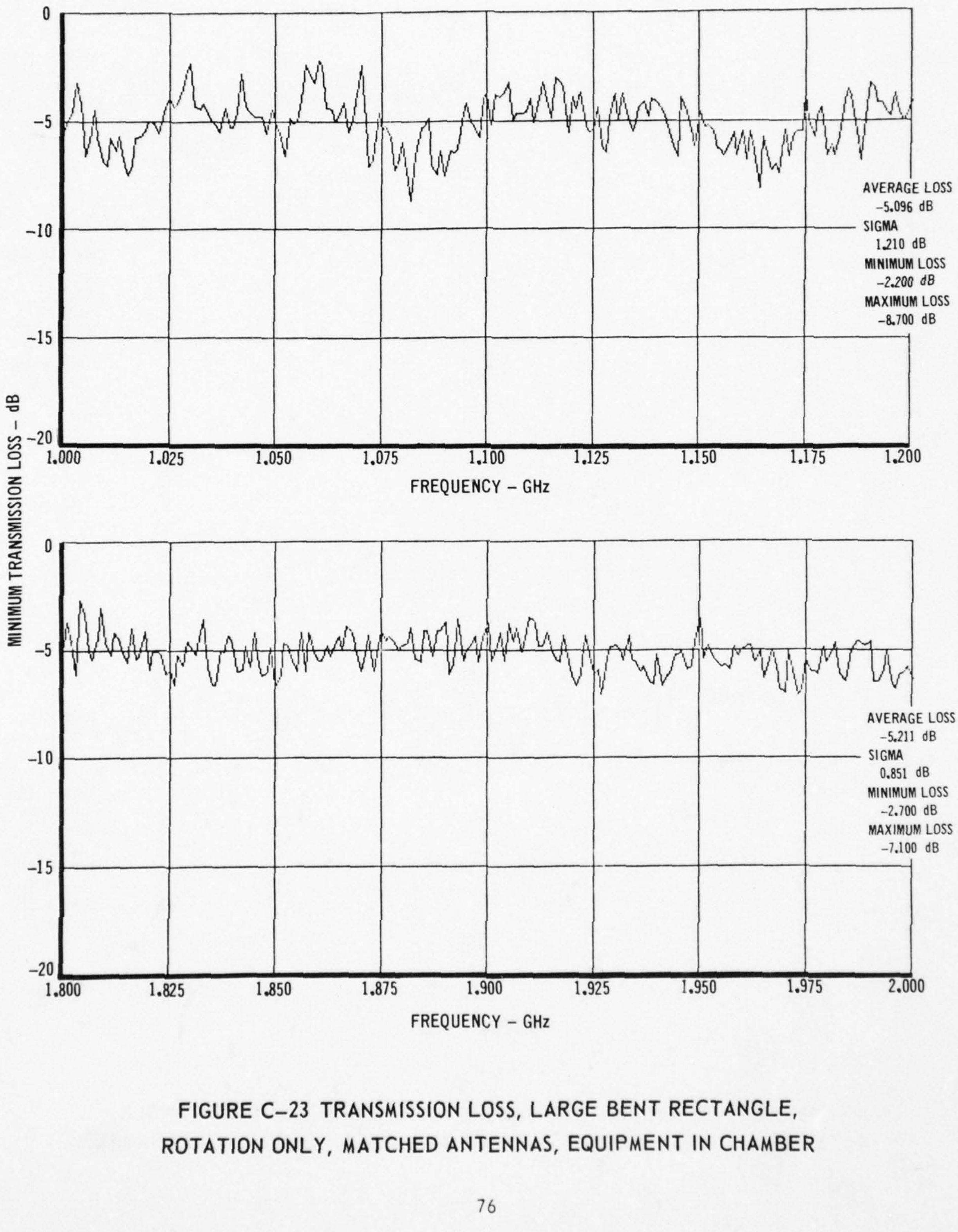
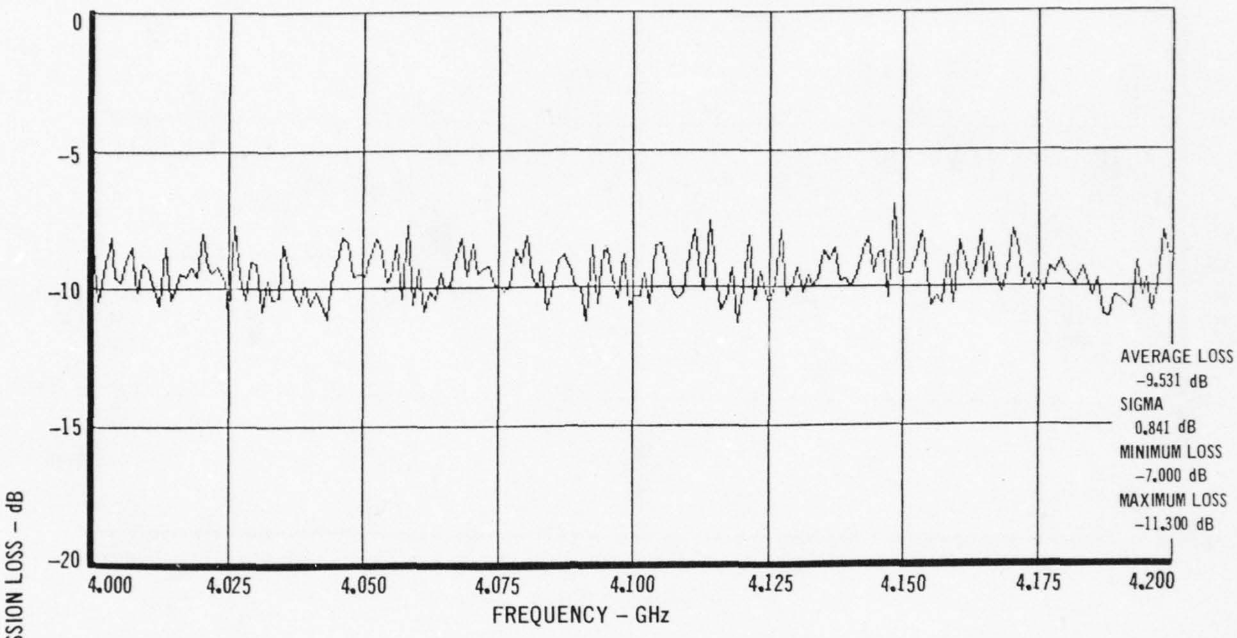


FIGURE C–23 TRANSMISSION LOSS, LARGE BENT RECTANGLE, ROTATION ONLY, MATCHED ANTENNAS, EQUIPMENT IN CHAMBER



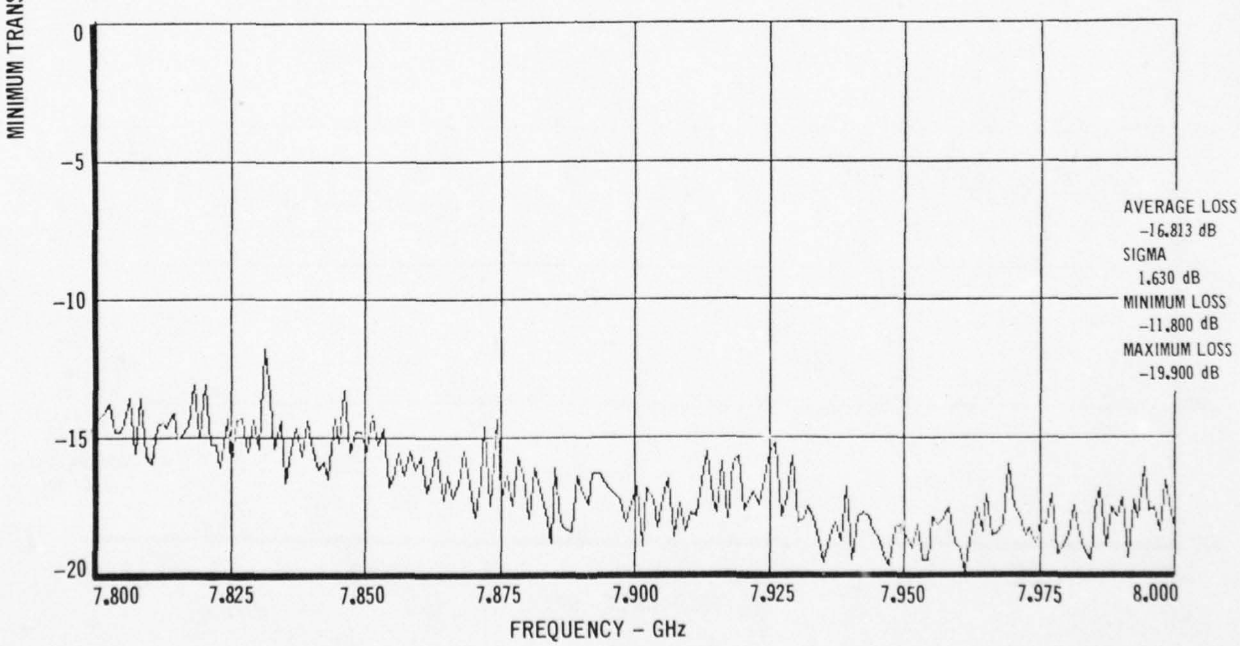


FIGURE C-24 TRANSMISSION LOSS, LARGE BENT RECTANGLE, ROTATION ONLY, MATCHED ANTENNAS, EQUIPMENT IN CHAMBER

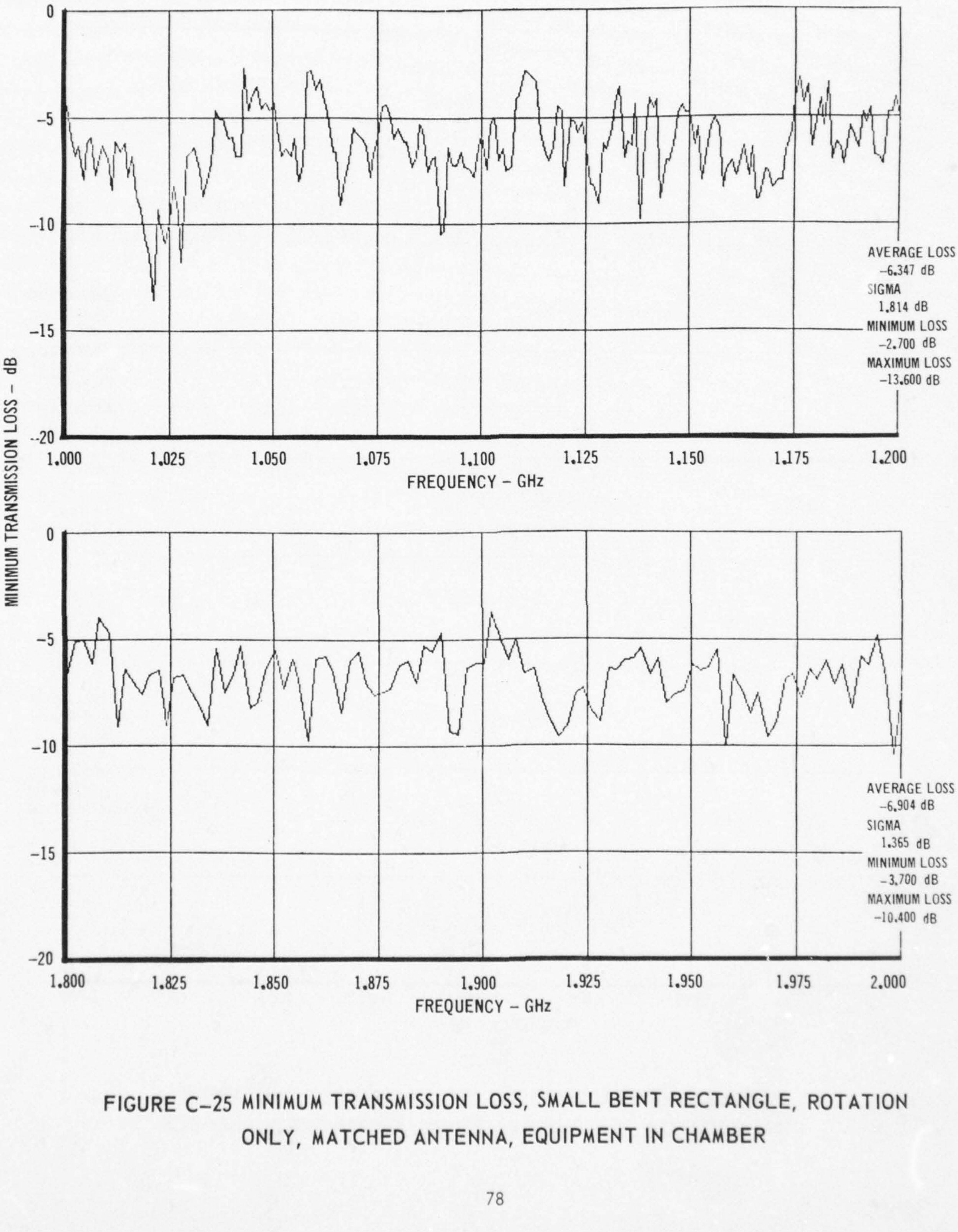


FIGURE C–25 MINIMUM TRANSMISSION LOSS, SMALL BENT RECTANGLE, ROTATION ONLY, MATCHED ANTENNA, EQUIPMENT IN CHAMBER

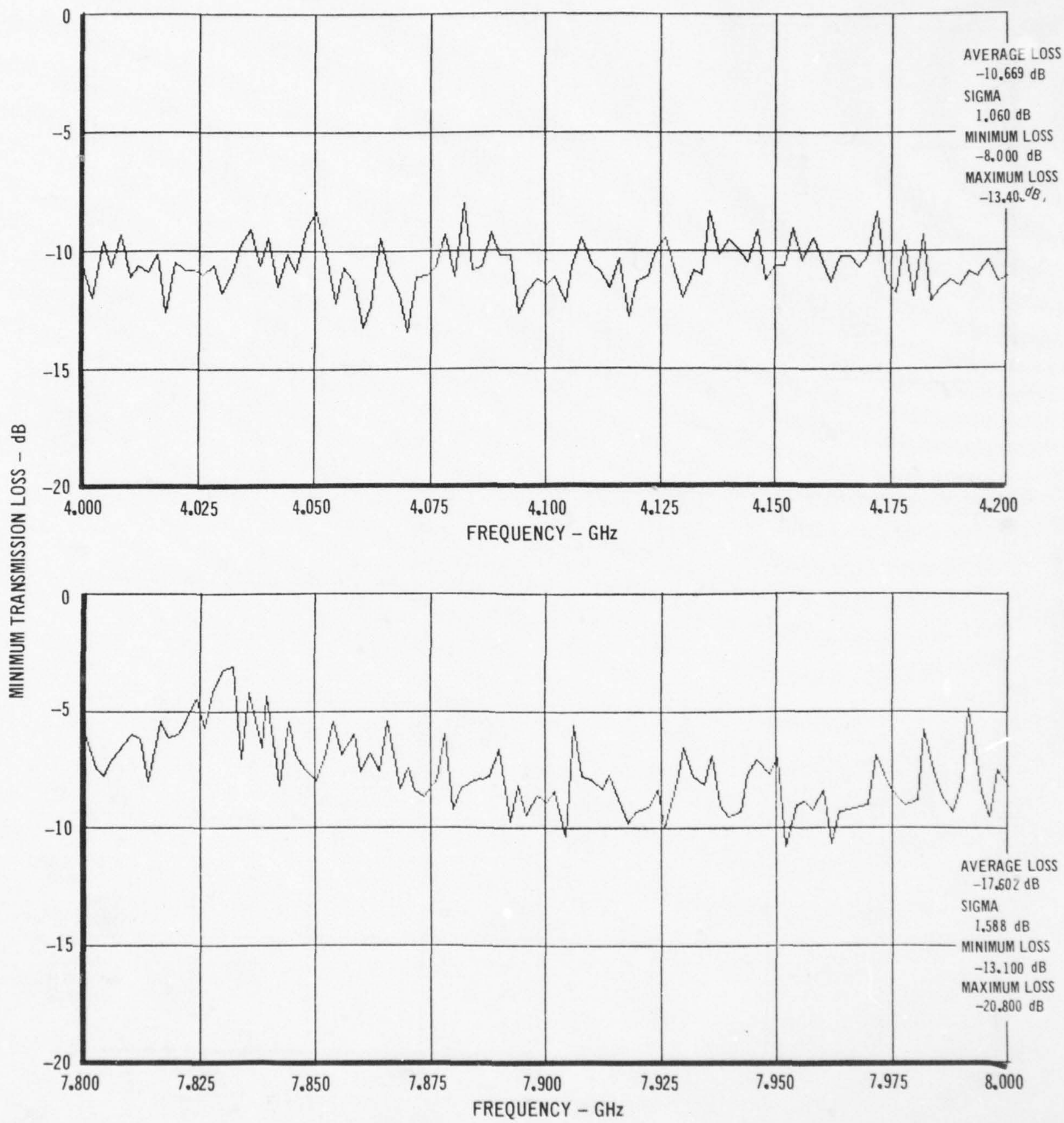


FIGURE C-26 MINIMUM TRANSMISSION LOSS, SMALL BENT RECTANGLE, ROTATION ONLY, MATCHED ANTENNA, EQUIPMENT IN CHAMBER

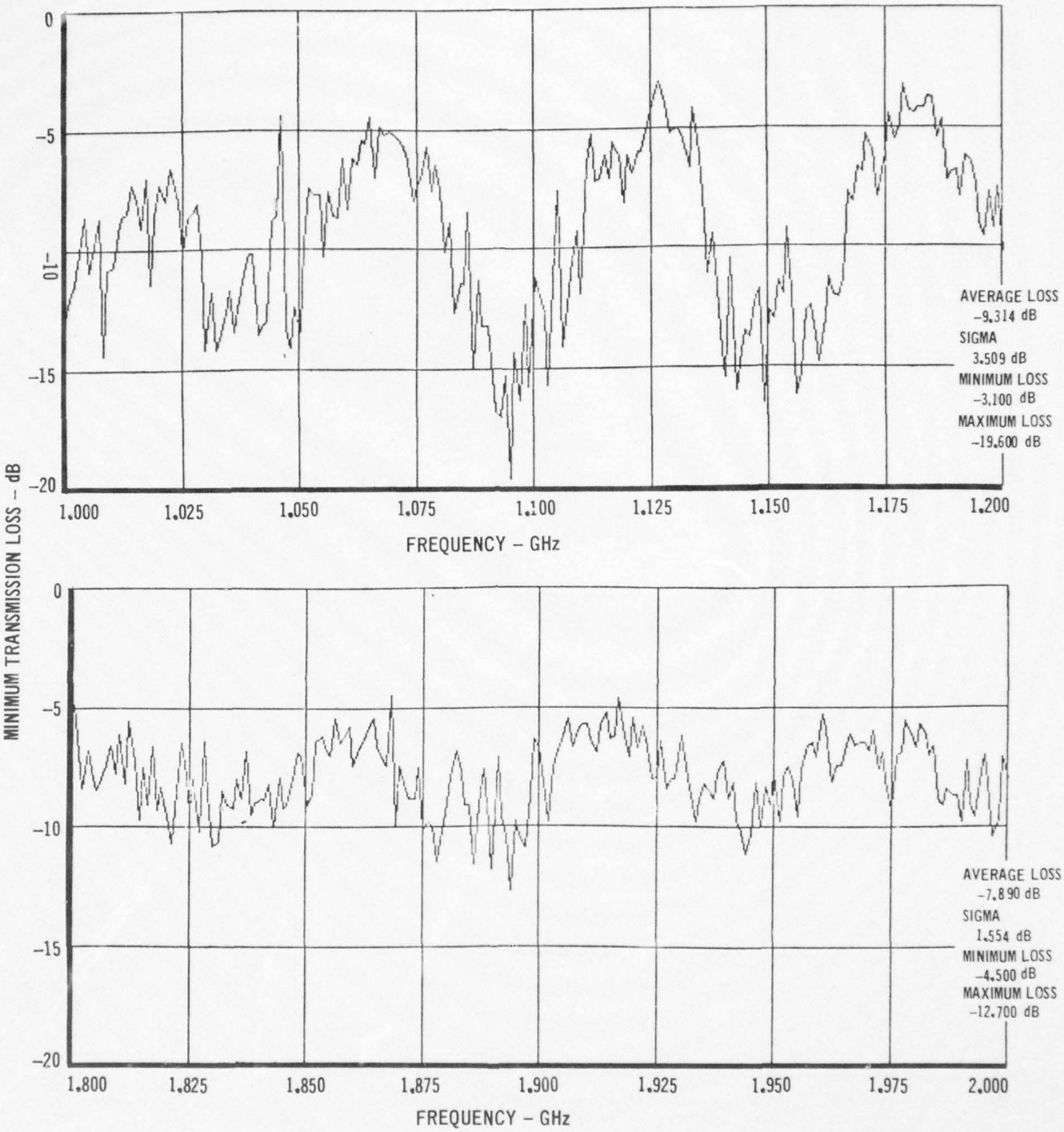


FIGURE C-27 MINIMUM TRANSMISSION LOSS, LARGE BENT RECTANGLE, ROTATION ONLY, UNMATCHED ANTENNA, EQUIPMENT IN CHAMBER

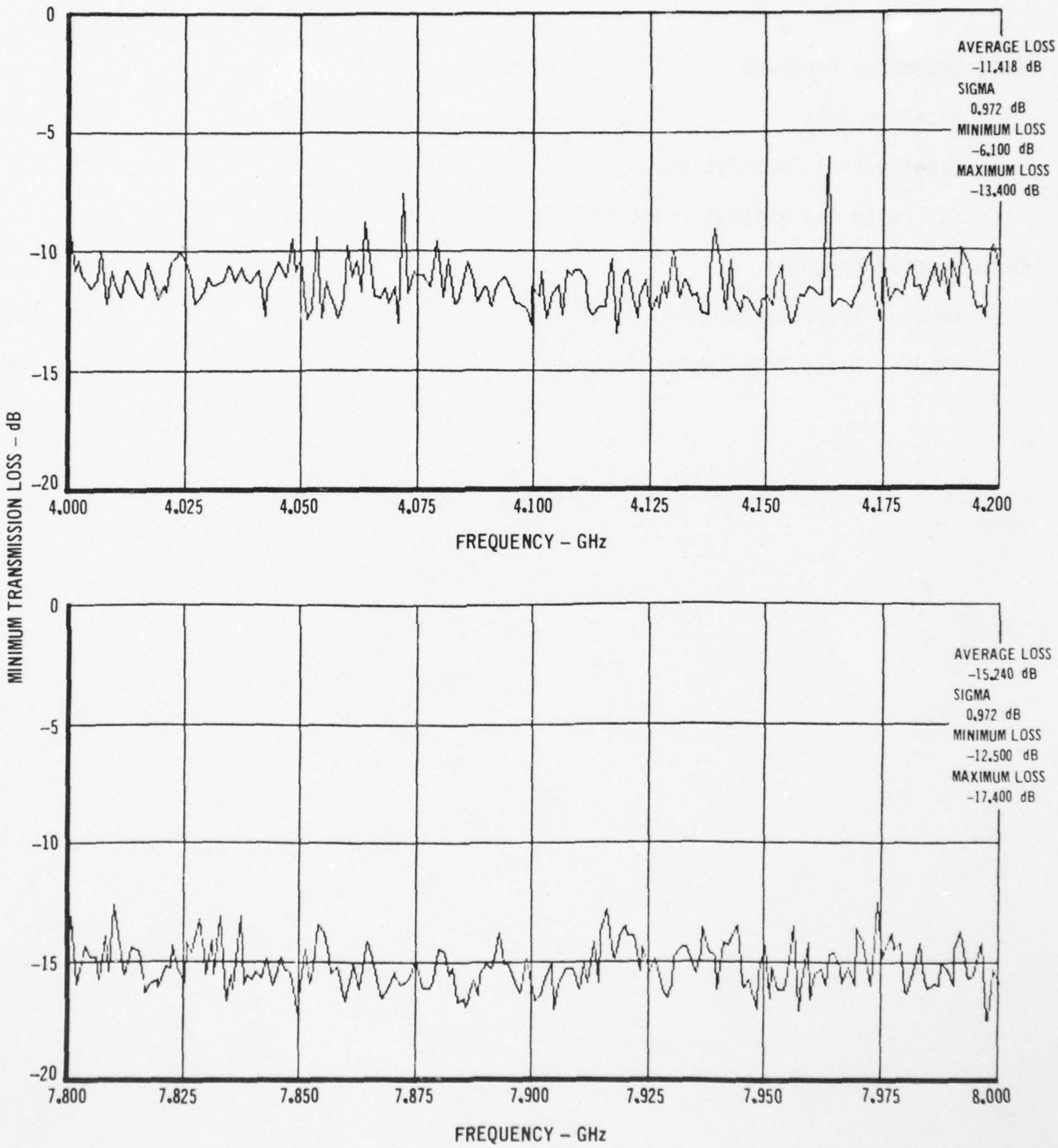


FIGURE C-28 MINIMUM TRANSMISSION LOSS, LARGE BENT RECTANGLE, ROTATION ONLY, UNMATCHED ANTENNA, EQUIPMENT IN CHAMBER

Appendix D

Computer program TEMEC provides the capability to automate EM chamber measurements when large amounts of data need to be gathered and analyzed in evaluating tuning improvements. The program is written in the Extended Fortran IV package provided for the Interdata Model 7/16 Mini-computer. A diagram of the test system is shown in Figure 3 of this report.

Figure D-1 is a flow chart of TEMEC 2 for one fan. The input data variables allow the program to be used at any frequency range, with various frequency increments and tolerances; program and testing control is also specified here. A printout of the program follows the flow chart.

Figure D-2 contains a flow chart of the two-tuner version of this program, and it is followed by a printout.

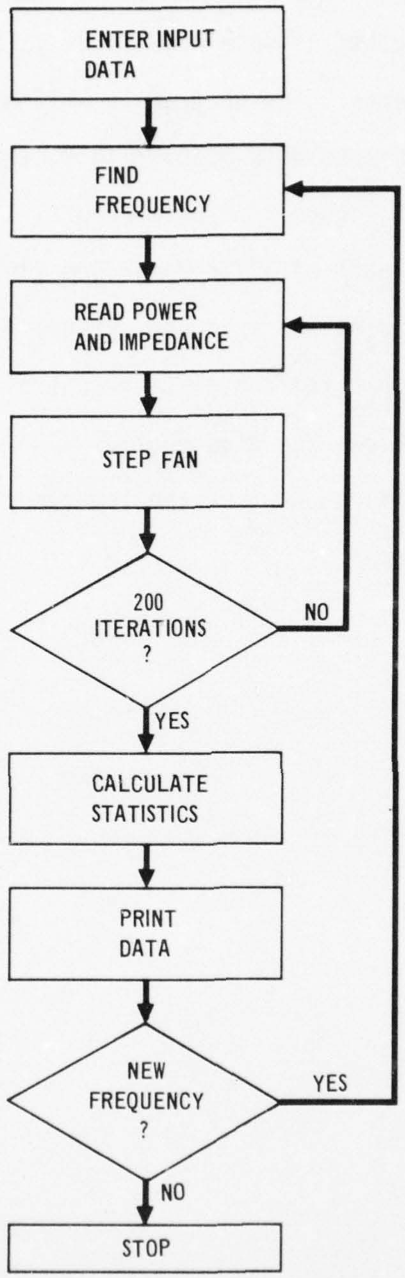


FIGURE D-1 FLOW CHART OF EM CHAMBER DATA-GATHERING COMPUTER PROGRAM

```
$LAB= TEMEC2
$DBUG
$TITL +++++  TEMEC2  +++++   SEPT 8,1976  SLOW SINGLE FAN VERSION
      REAL KURT,KURT1,METERF,METERP,LOWF,LFL
      INTEGER*2 SYM
      DIMENSION ZINHOR(200),ZINVER(200),POUTEN(200),A1(4),
     1J1(4),D1(614),D3(14)
      EQUIVALENCE (D1(1),ZINHOR(1)),(D1(201),ZINVER(1)),
     1(D1(401),POUTEN(1)),(D1(601),METERF),(D1(602),METERP),
     2(D1(603),NPASS),(D1(604),SUM1),(D1(605),SUM2),(D1(606),SUM3),
     3(D1(607),SUM4),(D1(608),AVE),(D1(609),SIGMA),(D1(610),SKEW),
     4(D1(612),PLARGE),(D1(611),KURT),(D3(1),D1(601))
      EQUIVALENCE (D1(613),NTAPE),(D1(614),NFILE)
      DATA CL/'?+%0'/,CT/'?+E '/
      WRITE(1,128)
      READ(1,125) NTFILE
      CALL FRFM(5,NTFILE)
      WRITE(1,36)
      READ(1,33) STARTF
      WRITE(1,76)
      READ(1,33) STOPF
      WRITE(1,77)
      READ(1,31) FINCRE
      WRITE(1,78)
      READ(1,31)FTOL
      WRITE(1,79)
      READ(1,31) RANGEF
      WRITE(1,121)
      READ(1,31) DBREF
      WRITE(1,123)
      READ(1,125) NTAPE
      WRITE(1,124)
      READ(1,125) NFILE
      WRITE(1,65)
      READ(1,125) IWAIT
      WRITE(2,63)
      WRITE(2,64) NTAPE,NFILE
      IF(FINCRE.EQ.0.) FINCRE=1.0
      J1(1)=5
      J1(2)=6
      J1(3)=7
      J1(4)=4
      FVOLT=0.0
      NZ=0
      INDEX=1+(STOPF-STARTF)/FINCRE
      DO 9 I=1,INDEX
      METERP=0.
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      PLARGE=-101.0
  108 HFL=STARTF+FTOL
      LFL=STARTF-FTOL
      WRITE(3) CL
      WRITE(3,101,ERR=108,END=108)
      WRITE(3) CT
      READ(3,102,ERR=108,END=108) SYM,VALUE
      METERF=VALUE/1000000.
      IF(METERF.GT.HFL) GO TO 103
      IF(METERF.LT.LFL) GO TO 104
      GO TO 105
  103 FVOLT=FVOLT-.004
```

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```
      GO TO 106
  104 FVOLT=FVOLT+.004
      GO TO 106
  106 OVOLT=FVOLT
      CALL AOUT(1,11,OVOLT,K)
      IF(K.NE.1) PAUSE 11
      CALL WAIT(50,1,M)
      IF(M.NE.1) PAUSE 1111
      GO TO 108
  105 DO 8 J=1,200
C     CALL WAIT(2,2,M)
      IF(M.NE.1) PAUSE 1111
   22 CALL AINHL(4,J1,A1,K)
      IF(K.NE.1) PAUSE 5674
      ZINHOR(J)=(A1(1)+.02)/2.055
      ZINVER(J)=(A1(2)+.03)/2.060
      POUTEN(J)=((A1(3)-1.5)/.05)+DBREF
      IF(A1(4).GT.0.82) GO TO 200
      IF(A1(4).LT.0.865) GO TO 200
      PAUSE 8
      GO TO 22
  200 IF(POUTEN(J).LE.-100.0) POUTEN(J)=-99.5
      RHO=SQRT((ZINHOR(J)**2)+(ZINVER(J)**2))
      IF(RHO.GT.1.) PAUSE 1
      IF (RHO-1.0) 26,26,22
   26 IF (POUTEN(J).LE.PLARGE) GO TO 16
      PLARGE=POUTEN(J)
      RHOLAR=RHO
   16 SUM1=SUM1+POUTEN(J)
      SUM2=SUM2+(POUTEN(J)**2)
      SUM3=SUM3+(POUTEN(J)**3)
      SUM4=SUM4+(POUTEN(J)**4)
      TEN=10.
      CALL AOUT(1,10,TEN,K)
      IF(K.NE.1) PAUSE 10
      CALL WAIT(IWAIT,1,N)
      IF(M.NE.1) PAUSE 1111
      ZERO=0.
      CALL AOUT(1,10,ZERO,K)
      IF(K.NE.1) PAUSE 10
      CALL WAIT(IWAIT,1,M)
      IF(M.NE.1) PAUSE 1111
    8 CONTINUE
      SUM5=SUM1/200.
      SUM6=SUM2/200.
      SUM7=SUM3/200.
      SUM8=SUM4/200.
      AVE=SUM5
      SIGMA=SQRT(SUM6-SUM5**2.)
      SKEW=(SUM7-(3.*SUM5*SUM6)+(2.*SUM5**3.))/SIGMA**3.
      KURT=(SUM8-(4.*SUM7*SUM5)+(6.*SUM6*SUM5**2.)-(3.*SUM5**4.))/
     1SIGMA**4.
      NPASS=I
      METERE=METERF+.5
      NMETER=INT(METERE)
      WRITE(2,60) NMETER,METERP,NPASS
      WRITE(2,61) SUM1,SUM2,SUM3,SUM4
      WRITE(2,120) PLARGE,RHOLAR
      WRITE(2,62) AVE, SIGMA,SKEW,KURT
      WRITE(5) D1
      FVOLT=FVOLT+(FINCRE*17.5)/(RANGEF*1000.)
      STARTF=STARTF+FINCRE
      MZ=MZ+1
```

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```
      IF(MZ.LT.8) GO TO 9
      WRITE(2,63)
      WRITE(2,122)
      WRITE(2,64) NTAPE,NFILE
      MZ=MZ-8
    9 CONTINUE
   31 FORMAT(F7.3)
   33 FORMAT(F6.0)
   36 FORMAT(1X,'ENTER START FREQUENCY, IN MHZ, IN THE FORM XXXXX.')
   60 FORMAT(1X,'FREQUENCY=',I6,' MHZ',5X,'POWER IN=',F7.3,' MW',
     15X,'PASS NUMBER ',I3)
   61 FORMAT(1X,'SUM1=',E13.6,' DB',9X,'SUM2=',E13.6,' DB SQUARED',
     11X,/1X,'SUM3=',E13.6,' DB CUBED',3X,'SUM4=',E13.6,
     2' DB TO THE FOURTH')
   62 FORMAT(1X,'AVE=',F8.3,' DB',5X,'SIGMA=',F8.3,' DB',5X,'SKEW=',
     1F8.3,5X,'KURT=',F8.3/)
   63 FORMAT(1H1)
   64 FORMAT(25X,'TEMEC TEST',5X,'TAPE NO. ',I4,5X,'FILE NO. ',I4)
   65 FORMAT('INPUT MSEC WAIT')
   76 FORMAT(1X,'ENTER STOP FREQ,IN MHZ, IN THE FORM XXXXX.')
   77 FORMAT(1X,'ENTER FREQ INCREMENT, IN MHZ, IN THE FORM XXX.XXX')
   78 FORMAT(1X,'ENTER FREQ TOLERANCE,IN MHZ,IN THE FORM XXX.XXX')
   79 FORMAT(1X,'ENTER HP8690 FREQ RANGE,IN GHZ,IN THE FORM XXX.XXX')
  101 FORMAT('5T@KMOH')
  102 FORMAT(A2,1X,E11.0)
  120 FORMAT(1X,'LARGEST POWER IN PASS=',F8.3,' DB',5X,'RHO=',F7.3)
  121 FORMAT(1X,'ENTER POWER-IN OFFSET,IN DB,IN THE FORM XXX.XXX')
  122 FORMAT(1X,/)
  123 FORMAT(1X,'ENTER TAPE NUMBER, IN THE FORM XXXX')
  124 FORMAT(1X,'ENTER FILE NUMBER, IN THE FORM XXXX')
  125 FORMAT(I4)
  128 FORMAT(1X,'ENTER NO. OF FILES TO SKIP, IN THE FORM XXXX')
   11 ENDFILE 5
   12 STOP
      END
ESTA TEMEC2
PRIO 9
OPTI 0010 1001 1001 0000
ASSI 1,10,2,0,3,3F,5,85,A,83
GET 200
LOAD
EDIT 506
MAP 62
TASK EC6
END
```

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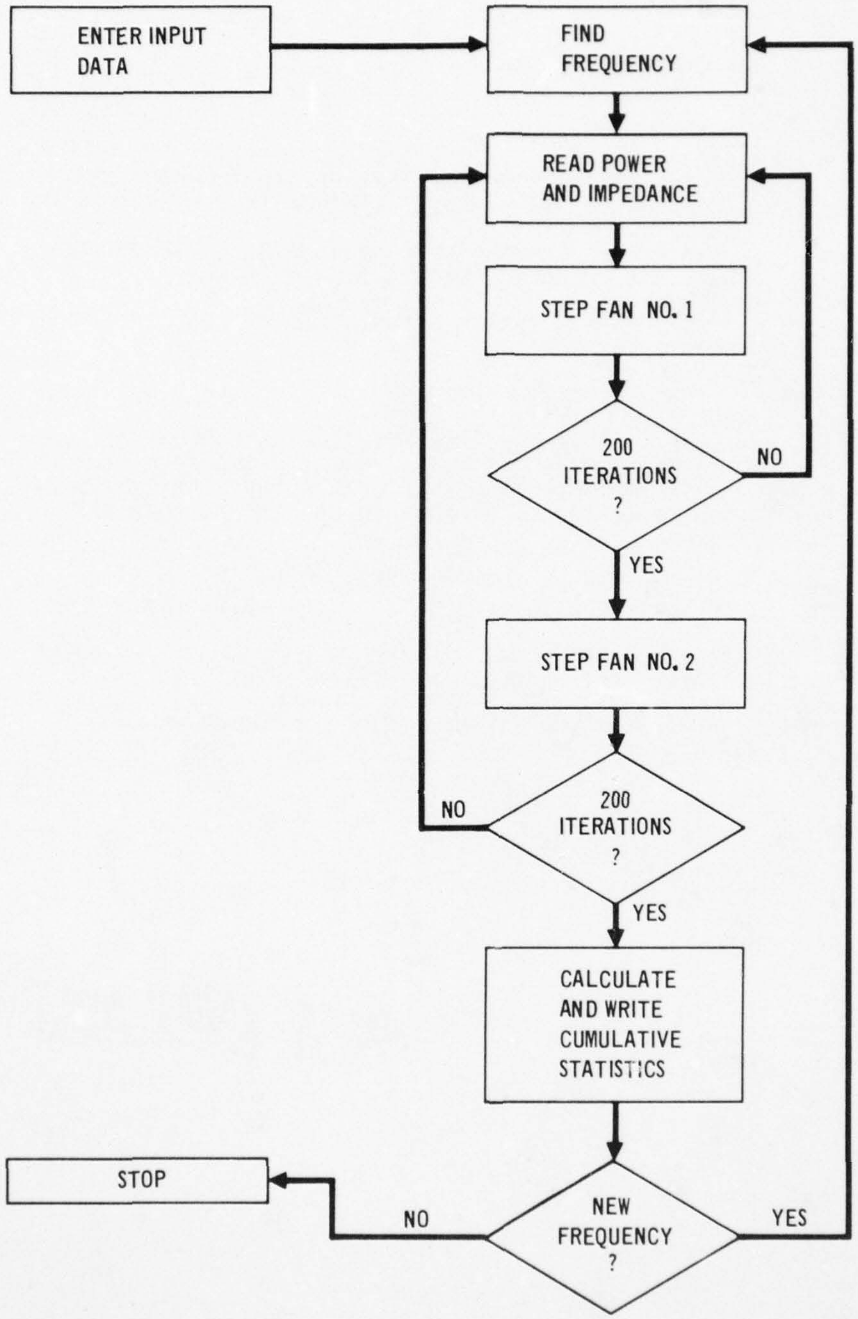

FIGURE D-2 FLOW CHART OF COMPUTER PROGRAM
TEMEC 2 – TWO TUNERS IN ROTATION VERSION

```
$LAB= TEMEC2
$DBUG
$TITL= +++++  TEMEC2  +++++  TWO FAN VERSION,  DECEMBER 3,1976
       REAL KURT,KURT1,METERF,METERP,LOWF,LFL,METERT
       INTEGER*2 SYM
       DIMENSION ZINHOR(200),ZINVER(200),POUTEN(200),A1(4),
      1J1(4),D1(614),D2(11),D3(14)
       EQUIVALENCE (D1(1),ZINHOR(1)),(D1(201),ZINVER(1)),
      1(D1(401),POUTEN(1)),(D1(601),METERF),(D1(602),METERP),
      2(D1(603),NPASS),(D1(604),SUM1),(D1(605),SUM2),(D1(606),SUM3),
      3(D1(607),SUM4),(D1(608),AVE),(D1(609),SIGMA),(D1(610),SKEW),
      4(D1(611),KURT),(D2(1),SUM9),(D2(2),SUM10),
      5(D2(3),SUM11),(D2(4),SUM12),(D2(5),AVE1),(D2(6),SIGMA1),
      6(D2(7),SKEW1),(D2(8),KURT1),(D2(9),NPASS1),(D2(10),METERT)
      7,(D1(612),PLARGE),(D2(11),TPLARG),(D3(1),D1(601))
       EQUIVALENCE (D1(613),NTAPE),(D1(614),NFILE)
       DATA CL/'?←%0'/,CT/'?←E '/
       WRITE(1,128)
       READ(1,125) NTFILE
       CALL FRFM(5,NTFILE)
       WRITE(1,36)
       READ(1,33) STARTF
       WRITE(1,76)
       READ(1,33) STOPF
       WRITE(1,77)
       READ(1,31) FINCRE
       WRITE(1,78)
       READ(1,31)FTOL
       WRITE(1,79)
       READ(1,31) RANGEF
       WRITE(1,121)
       READ(1,31) DBREF
       WRITE(1,123)
       READ(1,125) NTAPE
       WRITE(1,124)
       READ(1,125) NFILE
       IF(FINCRE.EQ.0.) FINCRE=1.0
       J1(1)=5
       J1(2)=6
       J1(3)=7
       J1(4)=4
       FVOLT=0.0
       INDEX=1+(STOPF-STARTF)/FINCRE
     1 MZ=0
       DO 15 IND=1,INDEX
       TPLARG=-101.0
       SUM9=0.0
       SUM10=0.0
       SUM11=0.0
       SUM12=0.0
       DO 9 I=1,200
       METERP=0.
       SUM1=0.
       SUM2=0.
       SUM3=0.
       SUM4=0.
       PLARGE=-101.0
   100 HFL=STARTF+FTOL
       LFL=STARTF-FTOL
       WRITE(3) CL
       WRITE(3,101)
       WRITE(3) CT
       READ(3,102) SYM,VALUE
```

```
      METERF=VALUE/1000000.
      IF(METERF.GT.HFL) GO TO 103
      IF(METERF.LT.LFL) GO TO 104
      GO TO 105
  103 FVOLT=FVOLT-.004
      GO TO 106
  104 FVOLT=FVOLT+.004.
      GO TO 106
  106 OVOLT=FVOLT
      CALL AOUT(1,11,OVOLT,K)
      IF(K.NE.1) PAUSE 11
      CALL WAIT(50,1,M)
      IF(M.NE.1) PAUSE 1111
      GO TO 108
  105 DO 8 J=1,200
C     CALL WAIT(2,2,M)
C     IF(M.NE.1) PAUSE 1111
   22 CALL AINHL(4,J1,A1,K)
      IF(K.NE.1) PAUSE 5674
      POUTEN(J)=((A1(3)-1.5)/.05)+DBREF
  200 IF(POUTEN(J).LE.-100.0) POUTEN(J)=-99.5
   26 IF (POUTEN(J).LE.PLARGE) GO TO 16
      PLARGE=POUTEN(J)
   16 SUM1=SUM1+POUTEN(J)
      SUM2=SUM2+(POUTEN(J)**2)
      SUM3=SUM3+(POUTEN(J)**3)
      SUM4=SUM4+(POUTEN(J)**4)
      TEN=10.
      CALL AOUT(1,10,TEN,K)
      IF(K.NE.1) PAUSE 10
      CALL WAIT(1,1,M)
      IF(M.NE.1) PAUSE 1111
      ZERO=0.
      CALL AOUT(1,10,ZERO,K)
      IF(K.NE.1) PAUSE 10
      CALL WAIT(1,1,M)
      IF(M.NE.1) PAUSE 1111
    8 CONTINUE
      IF (PLARGE.LE.TPLARG) GO TO 3
      TPLARG=PLARGE
      METERT=METERF
    3 CONTINUE
  119 SUM9=SUM9+SUM1
      SUM10=SUM10+SUM2
      SUM11=SUM11+SUM3
      SUM12=SUM12+SUM4
      SUM5=SUM1/200.
      SUM6=SUM2/200.
      SUM7=SUM3/200.
      SUM8=SUM4/200.
      AVE=SUM5
      SIGMA=SQRT(SUM6-SUM5**2.)
      SKEW=(SUM7-(3.*SUM5*SUM6)+(2.*SUM5**3.))/SIGMA**3.
      KURT=(SUM8-(4.*SUM7*SUM5)+(6.*SUM6*SUM5**2.)-(3.*SUM5**4.))/
     1SIGMA**4.
      NPASS=I
      METERE=METERF+.5
      NMETER=INT(METERE)
C     WRITE(5) D1
   27 TEN=10.
      CALL AOUT(1,9,TEN,K)
      IF(K.NE.1) PAUSE 9
      CALL WAIT(1,1,M)
```

```
      IF(M.NE.1) PAUSE 1111
      ZERO=0.
      CALL AOUT(1,9,ZERO,K)
      IF(K.NE.1) PAUSE 9
      CALL WAIT(1,1,M)
      IF(M.NE.1) PAUSE 1111
    9 CONTINUE
      SUM13=SUM9/40000.
      SUM14=SUM10/40000.
      SUM15=SUM11/40000.
      SUM16=SUM12/40000.
      AVE1=SUM13
      SIGMA1=SQRT(SUM14-SUM13**2.)
      SKEW1=(SUM15-(3.*SUM13*SUM14)+(2.*SUM13**3.))/SIGMA1**3.
      KURT1=(SUM16-(4.*SUM13*SUM15)+(6.*SUM14*SUM13**2.)-(3.*SUM13**4.)
     1)/SIGMA1**4.
      NPASS1=202
      WRITE(5) D2
C     ENDFILE 5
      STARTF=STARTF+FINCRE
   15 FVOLT=FVOLT+(FINCRE*17.5)/(RANGEF*1000.)
      ENDFILE 5
   31 FORMAT(F7.3)
   33 FORMAT(F6.0)
   36 FORMAT(1X,'ENTER START FREQUENCY, IN MHZ, IN THE FORM XXXXX.')
   76 FORMAT(1X,'ENTER STOP FREQ,IN MHZ, IN THE FORM XXXXX.')
   77 FORMAT(1X,'ENTER FREQ INCREMENT,IN MHZ,IN THE FORM XXX.XXX)←')
   78 FORMAT(1X,'ENTER FREQ TOLERANCE,IN MHZ,IN THE FROM ZXX.XXX')
   79 FORMAT(1X,'ENTER HP8690 FREQ RANGE,IN GHZ,IN THE FORM XXX.XXX')
  101 FORMAT('ST@KMOH')
  102 FORMAT(A2,1X,E11.0)
  121 FORMAT(1X,'ENTER POWER-IN OFFSET,IN DB,IN THE FORM XXX.XXX')
  123 FORMAT(1X,'ENTER TAPE NUMBER, IN THE FORM XXXX')
  124 FORMAT(1X,'ENTER FILE NUMBER, IN THE FORM XXXX')
  125 FORMAT(I4)
  128 FORMAT(1X,'ENTER NO. OF FILES TO SKIP, IN THE FORM XXXX')
   12 STOP
      END
ESTA TEMEC2
PRIO 9
OPTI 0010 1001 1001 0000
ASSI 1,10,2,0,3,3F,5,85,A,83
GET 200
LOAD
EDIT 506
MAP 62
TASK 07
END
```

Two computer programs for testing the EM chamber with longitudinal translation of a paddlewheel have been written. A flow chart and printout of the first program, LONGIT, start with Figure D-3. This program positions the carrier output translator, and hence the field tuner, every tenth of a wavelength of each test frequency, and, as the tuner is rotated at these positions, it checks for the lowest transmission loss at each of these positions. After running the full length of the translator (about 6 inches or 15 centimeters), the carrier is returned to the position with the lowest transmission loss of all the positions. It is then assumed that the carrier (and tuner) is in the vicinity of a transmission loss minimum. Therefore, the program looks at 6 other carrier locations, 3 on either side of its current position, for a total of 7 positions. These locations are 1 thread (18 threads/inch) apart, and at each location, the tuner is rotated and a minimum transmission loss is obtained. The carrier returns to the best of these 7 positions, and the tuner rotated to its lowest transmission loss point; this value is then recorded.

The second computer program, LONGON, looks for a minimum transmission loss along the entire length of the translator, without rotating the tuner, at a frequency of 3600 longitudinal positions per inch. This program investigates the effects of longitudinal translation alone to look at transmission loss as a function of longitudinal position, and to determine if rotation of the field tuners does give a smaller transmission loss when compared to longitudinal translation only. Figure D-4 is a flow chart of LONGON, and is followed by a printout of the program.

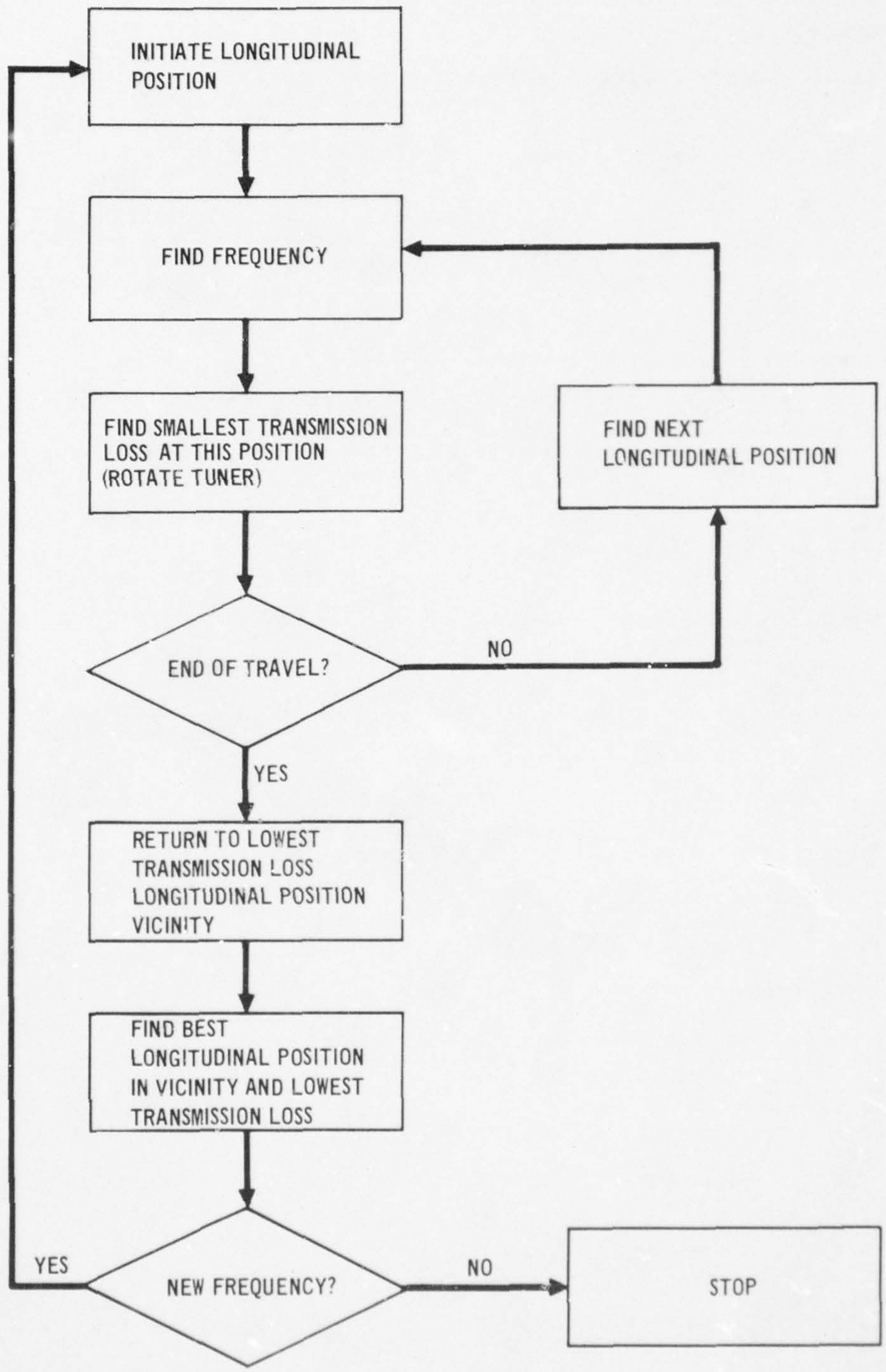

FIGURE D-3 FLOW CHART OF LONGITUDINAL TRANSLATION PLUS ROTATION COMPUTER PROGRAM 'LONGIT'

AD-A051 222 MCDONNELL DOUGLAS ASTRONAUTICS CO-EAST ST LOUIS MO F/G 14/2

ELECTROMAGNETIC CHAMBER MODIFICATIONS AND MEASUREMENTS.(U)

MAR 77 D I HARPRING, R L JUDE, J M ROE N60921-76-C-A273

UNCLASSIFIED MDC-E1637 NSWC/DL-TR-3641 NL

2 OF 2
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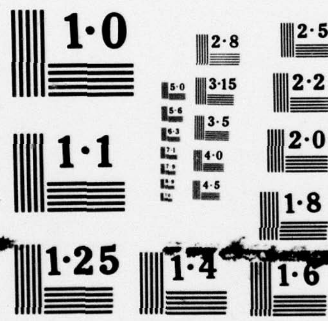
1·0
2·8
2·5
3·15
2·2
3·5
2·0
4·0
1·1
4·5
1·8
1·25
1·4
1·6

```
$LAB= LONGIT
$DBUG
$TITL= +++++  LONGIT  +++++      OCTOBER 6,1976, 1976
C                                         A/D  8--HP 8690 FM INPUT
C                                         A/D  9--ROTATE FAN CW
C                                         A/D 10--ROTATE FAN CCW
C                                         A/D 11--FORWARD MOTION (CW)
C                                         A/D 12--REVERSE MOTION (CCW)
C                                         JIN(1)--STOP REVERSE MOTION
C                                         JIN(2)--STOP FORWARD MOTION
C                                         ASSIGNMENTS--1,10/2,2/3,3F/
C                                                      4,55/5,85/6,62/
C                                                      7,0/A,83/
      REAL LFL
      DIMENSION D(220),D1(200),JIN(2),AIN(2)
      INTEGER*2 SYM
      EQUIVALENCE (D(1),NTAPE),(D(2),NFILE),(D(3),FMETER),
     1(D(4),JNUM),(D(5),K),(D(6),X),(D(7),XP)
     2,(D(8),IBACK),(D(9),STEP1),(D(10),LSTEP),(D(11),STARTF),
     3(D(12),NPOS),(D(13),INDEX),(D(14),NPOS1),(D(15),NSTEP),
     4(D(16),X1),(D1(1),D(21))
      DATA CL/''?+%@'/,CT/''?+E '/
      DATA (D(I),I=17,20)/4*0.0/
      JIN(1)=5
      JIN(2)=6
      CM=3600./2.54
      FINCRE=2.0
      FTOL=0.2
      RANGEF=2.0
      NWAVE=10
C     WRITE(1,66)
C     READ(1,67) NCHANG
      WRITE(1,80)
      READ(1,79) NSKIP
      CALL FRFM(5,NSKIP)
      WRITE(1,77)
      READ(1,79) NTAPE
      WRITE(1,78)
      READ(1,79) NFILE
      WRITE(1,68)
      READ(1,51) STARTF
      WRITE(1,69)
      READ(1,51) STOPF
C     IF(NCHANG.NE.1) GO TO 39
      WRITE(1,70)
      READ(1,52) FINCRE
      WRITE(1,71)
      READ(1,52) FTOL
      WRITE(1,72)
      READ(1,52) RANGEF
      WRITE(1,53)
      READ(1,54) NWAVE
   39 IF(FINCRE.EQ.0.0) FINCRE=1.0
      IND40=1+(STOPF-STARTF)/FINCRE
      FVOLT=0.0
      WRITE(4,81) NTAPE,NFILE,STARTF
      DO 40 IIND=1,IND40
      K=0
      IBACK=0
      NPOS=0
      XP=-1000.
      JSTEP=1
      JNUM=0
```

```
      NFR=0
      X1=0
      INDEX=0
      NPOS1=0
      NSTEP=0
      STEP1=30000./STARTF
      LSTEP=(CM*STEP1)/NWAVE
C     WRITE(7,75)
C     WRITE(6,73) STARTF,STEP1
C     WRITE(6,56) LSTEP
C                                          INITIATE LONGITUDINAL
C                                          POSITION
      I=0
      J=0
    2 CALL AINHL(2,JIN,AIN,KERR)
      IF(KERR.NE.1) PAUSE 506
      I=I+1
      IF(I.LT.10) GO TO 1
      CALL STEP(9,1,0)
      I=0
    1 IF(J.GT.205) GO TO 35
      J=J+1
      IF(J.LT.200) GO TO 34
   35 IF(AIN(2).GT.1.0) PAUSE 1
   34 IF(AIN(1).GT.1.0) GO TO 106
      CALL STEP(12,1,3)
      GO TO 2
C                                          FIND FREQUENCY
  106 OVOLT=FVOLT
      CALL AOUT(1,8,OVOLT,KERR)
      IF(KERR.NE.1) PAUSE 7777
      CALL WAIT(50,1,MERR)
      IF(MERR.NE.1) PAUSE 1111
      HFL=STARTF+FTOL
      LFL=STARTF-FTOL
    3 WRITE(3) CL
      WRITE(3,101,ERR=106,END=106)
      WRITE(3) CT
      READ(3,102,ERR=106,END=106) SYM,VALUE
      FMETER=VALUE/1000000.
      IF(FMETER.GT.HFL) GO TO 103
      IF(FMETER.LT.LFL) GO TO 104
      IF(NFR.EQ.1) GO TO 45
      GO TO 105
  103 FVOLT=FVOLT-.004
      GO TO 106
  104 FVOLT=FVOLT+.004
      GO TO 106
C                                          FIND SMALLEST
C                                          TRANSMISSION LOSS AT THIS
C                                          POSITION
  105 X=-1000.
      DO 4 I=1,600
      CALL AINHL(1,7,P,KERR)
      IF(KERR.NE.1) PAUSE 7
      P=(P-1.5)/.05
      IF(I.LE.400) GO TO 43
      D(I-300)=P
   43 IF(P.LE.X) GO TO 36
      X=P
   36 CALL STEP(9,1,5)
    4 CONTINUE
      JNUM=JNUM+1
```

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```
C       WRITE(6,55) JNUM,X
        IF(X.LE.XP) GO TO 5
        XP=X
        NPOS=JSTEP
      5 WRITE(5) D
        IF(IBACK.NE.0) GO TO 15
C                                             FIND NEXT LONGITUDINAL
C                                             POSITION
        I=0
        DO 10 J=1,LSTEP
        I=I+1
        CALL STEP(11,1,3)
        CALL AINHL(2,JIN,AIN,KERR)
        IF(KERR.NE.1) PAUSE 506
        IF(I.NE.10) GO TO 11
        CALL STEP(9,1,0)
        I=0
     11 IF(JSTEP.EQ.1.AND.J.LT.200) GO TO 6
        IF(AIN(1).GT.1.0) PAUSE 1005
      6 IF(AIN(2).GT.1.0) GO TO 12
     10 CONTINUE
        GO TO 16
     12 IBACK=J
C       WRITE(6,57) IBACK
     16 JSTEP=JSTEP+1
        GO TO 3
C                                            RETURN TO LOWEST TRANSMIS-
C                                            SION LOSS LONGITUDINAL
C                                            POSITION
C    15 WRITE(6,63) NPOS
     15 JNUM=NPOS
        NSTOP=JSTEP-NPOS
        IF(NSTOP.EQ.0) GO TO 18
        L=0
        DO 17 M=1,NSTOP
        NSTEP=LSTEP
        IF(M.EQ.1) NSTEP=IBACK
        I=0
        DO 17 J=1,NSTEP
        IF(L.LE.205) L=L+1
        I=I+1
        CALL STEP(12,1,3)
        CALL AINHL(2,JIN,AIN,KERR)
        IF(KERR.NE.1) PAUSE 506
        IF(I.NE.10) GO TO 7
        CALL STEP(9,1,0)
        I=0
      7 IF(L.LT.200) GO TO 17
        IF(NPOS.EQ.1) GO TO 17
        IF(AIN(1).GT.1.0.OR.AIN(2).GT.1.0) PAUSE 2222
     17 CONTINUE
        GO TO 20
     18 INDEX=4
        GO TO 21
     20 NSTEP=600
        LSTEPX=IBACK+LSTEP
        IF(NSTOP.EQ.1.AND.IBACK.LT.600) NSTEP=IBACK
        IF(NSTOP.EQ.2.AND.LSTEPX.LT.600) NSTEP=LSTEPX
     22 CALL WAIT(1,2,MERR)
        IF(MERR.NE.1) PAUSE 1111
        I=0
        DO 13 J=1,NSTEP
        I=I+1
```

```
      CALL STEP(11,1,3)
      CALL AINHL(2,JIN,AIN,KERR)
      IF(KERR.NE.1) PAUSE 506
      IF(I.NE.10) GO TO 9
      CALL STEP(9,1,0)
      I=0
    9 IF(NSTOP.EQ.1.AND.IBACK.LE.700) GO TO 13
      IF(NSTOP.EQ.2.AND.LSTEPX.LE.700) GO TO 13
      IF(NPOS.EQ.1.AND.J.LT.200) GO TO 13
      IF(AIN(1).GT.1.0.OR.AIN(2).GT.1.0) PAUSE 4444
   13 CONTINUE
      INDEX=7
      KSTEP=0
      IF(NPOS.EQ.1) INDEX=4
      IF(NPOS.EQ.2.AND.LSTEP.LT.600) KSTEP=LSTEP-400
      IF(NSTOP.GT.2) GO TO 21
      IF(NSTOP.EQ.1.AND.IBACK.GE.600) GO TO 21
      IF(NSTOP.EQ.2.AND.LSTEPX.GE.600) GO TO 21
      IF(NSTOP.EQ.2) GO TO 19
      XIBACK=FLOAT(IBACK)
      XN=XIBACK/200.
      INDEX=5+INT(XN)
      IBACK=IBACK-200*INT(XN)
      GO TO 21
   19 XLSTEP=FLOAT(LSTEPX)
      XN=XLSTEP/200.
      INDEX=5+INT(XN)
      LSTEPX=LSTEPX-200*INT(XN)
C                                             FIND BEST LONGITUDINAL
C                                             POSITION
   21 NFR=1
      GO TO 106
   45 XT=-1000.
C     WRITE(6,58)
C     WRITE(6,65) INDEX
      DO 24 K=1,INDEX
      X=-1000.
      DO 23 I=1,400
      CALL AINHL(1,7,P,KERR)
      IF(KERR.NE.1) PAUSE 7
      P=(P-1.5)/.05
      IF(I.LE.200) GO TO 44
      D(I-180)=P
   44 IF(P.LE.X) GO TO 37
      X=P
   37 CALL STEP(9,1,5)
   23 CONTINUE
C     WRITE(6,60) K,X
      IF(X.LE.XT) GO TO 30
      XT=X
      NPOS1=K
   30 IND24=200
      IF(XT.GT.XP)  XP=XT
      WRITE(5) D
      IF(K.EQ.1.AND.NSTOP.EQ.1.AND.IBACK.LT.600) IND24=IBACK
      IF(K.EQ.1.AND.NSTOP.EQ.2.AND.LSTEPX.LT.600) IND24=LSTEPX
      IF(K.EQ.1) INKEEP=IND24
      IF(NPOS.EQ.1.AND.K.EQ.INDEX) GO TO 24
      IF(NPOS.EQ.2.AND.K.EQ.INDEX.AND.LSTEP.LT.600) GO TO 24
      IF(NPOS.EQ.2.AND.K.EQ.INDEX-1.AND.LSTEP.LT.600) IND24=KSTEP
C     WRITE(6,64) IND24
      M=0
      DO 49 J=1,IND24
```

```
      M=M+1
      CALL STEP(12,1,3)
      CALL AINHL(2,JIN,AIN,KERR)
      IF(KERR.NE.1) PAUSE 506
      IF(M.NE.10) GO TO 32
      CALL STEP(9,1,0)
      M=0
   32 IF(NPOS.EQ.1.AND.INDEX.EQ.4) GO TO 49
      IF(NPOS.EQ.2.AND.K.EQ.INDEX-1) GO TO 49
      IF(K.LE.2.AND.NSTOP.LE.2) GO TO 49
      IF(K.EQ.INDEX.AND.LSTEP.LT.700) GO TO 49
      IF(AIN(1).GT.1.0.OR.AIN(2).GT.1.0) PAUSE 5555
   49 CONTINUE
   24 CONTINUE
      NKEEP=0
      IF(NPOS1.EQ.1) NKEEP=200-INKEEP
      NSTEP=200*(INDEX+1-NPOS1)-NKEEP
      IF(NPOS.EQ.1) NSTEP=NSTEP-200
      IF(NPOS.EQ.2.AND.KSTEP.NE.0) NSTEP=NSTEP-400+KSTEP
      IF(NSTEP.LT.0) NSTEP=0
      IF(NSTEP.EQ.0) GO TO 14
      I=0
      CALL WAIT(1,2,MERR)
      IF(MERR.NE.1) PAUSE 1111
      DO 31 K=1,NSTEP
      I=I+1
      CALL STEP(11,1,3)
      CALL AINHL(2,JIN,AIN,KERR)
      IF(KERR.NE.1) PAUSE 506
      IF(I.NE.10) GO TO 33
      CALL STEP(9,1,0)
      I=0
   33 IF(K.LT.200.OR.NSTOP.LE.2) GO TO 31
      IF(AIN(1).GT.1.0.OR.AIN(2).GT.1.0) PAUSE 6666
   31 CONTINUE
C  14 WRITE(6,61) NPOS1,NSTEP
   14 JINDEX=1
C                                          FIND SMALLEST TRANSMISSION
C                                          LOSS
   29 X=-1000.
      DO 25 I=1,200
      CALL AINHL(1,7,P,KERR)
      IF(KERR.NE.1) PAUSE 7
      P=(P-1.5)/.05
      D1(I)=P
      IF(P.LE.X) GO TO 38
      X=P
      ISTEP=I-1
   38 CALL STEP(9,1,5)
   25 CONTINUE
      IF(X.LE.XP) GO TO 8
      XP=X
    8 IF(JINDEX.EQ.1) GO TO 27
C     IF(ISTEP.EQ.0) GO TO 27
C     JINDEX=1
   27 NSTEP=195+ISTEP
      DO 41 I=1,NSTEP
      CALL STEP(9,1,3)
   41 CONTINUE
      X1=-1000.
      DO 26 I=1,11
      CALL WAIT(1,2,MERR)
      IF(MERR.NE.1) PAUSE 1111
```

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```
      CALL AINHL(1,7,P,KERR)
      IF(KERR.NE.1) PAUSE 7
      P=(P-1.5)/.05
      IF(P.LE.X1) GO TO 26
      X1=P
      ISTEP=I
   26 CALL STEP(9,1,0).
      IF(X1.LE.XP) GO TO 42
      XP=X1
C  42 WRITE(6,62) X1
   42 WRITE(5) D
      NSTEP=12-ISTEP
      CALL STEP(10,NSTEP,3)
      JINDEX=JINDEX+1
      IF(JINDEX.LE.2) GO TO 29
   28 CALL AINHL(1,7,XP1,KERR)
      IF(KERR.NE.1) PAUSE 7
      XP1=(XP1-1.5)/.05
C     WRITE(6,74) XP1
      WRITE(2,59) FMETER,XP
C     WRITE(6,59) FMETER,XP
      WRITE(4,76) FMETER,XP
      FVOLT=FVOLT+(FINCRE*17.5)/(RANGEF*1000.)
   40 STARTF=STARTF+FINCRE
      ENDFILE 4
      ENDFILE 5
   51 FORMAT(F6.0)
   52 FORMAT(F7.3)
   53 FORMAT(1X,'ENTER NO. OF LONG. POSITIONS/WAVELENGTH, I2')
   54 FORMAT(I2)
C  55 FORMAT(1X,'AT LONGITUDINAL POSITION',I3,',   X=',F8.3)
C  56 FORMAT(1X,'FULL LONGITUDINAL INCREMENT =,',I5,' STEPS')
C  57 FORMAT(1X,'END OF FORWARD TRAVEL REACHED.    IBACK=',I5)
C  58 FORMAT(1X,'RETURN TO BEST LONGITUDINAL AREA COMPLETE')
   59 FORMAT(1X,'FREQUENCY=',F7.0,' MHZ',5X,'XP=',F8.3)
C  60 FORMAT(1X,'FINAL ITERATION INDEX=',I2,'.   X=',F8.3)
C  61 FORMAT(1X,'FINAL LONGITUDINAL POSITION REACHED.  NPOS=',I2,'  NSTE
C    1P=',I5)
C  62 FORMAT(10X,'X1=',F8.3)
C  63 FORMAT(1X,'RETURNING TO LONGITUDINAL POSITION',I3)
C  64 FORMAT(1X,'IND24=',I4)
C  65 FORMAT(29X,'INDEX=',I2)
C  66 FORMAT(///'PROGRAM  ++ LONGIT ++  ASSUMES THE FOLLOWING DEFAULT VA
C    1LUES:'///10X,'VARIABLE',9X,'DESCRIPTION',9X,'DEFAULT VALUE'//11X,'
C    7STARTF',6X,                                                        '
C    2START FREQUENCY',12X,'NONE'/11X,'STOPF',7X,'STOP FREQUENCY',13X,'N
C    3ONE'/11X,'FINCRE',6X,'FREQUENCY INCREMENT',8X,'2.0 MHZ'/11X,'FTOL'
C    4,8X,'FREQUENCY TOLERANCE',8X,'0.2 MHZ'/11X,'RANGEF',6X,'HP 8690 FR
C    5EQ. RANGE',8X,'2.0 MHZ'/11X,'NWAVE',7X,'SAMPLES/WAVELENGTH',9X,'10
C    6'//1X,'IF YOU WISH TO CHANGE THE DEFAULT VALUES,TYPE "1".')
   67 FORMAT(I1)
   68 FORMAT(1X,'ENTER START FREQ., IN MHZ, F6.0')
   69 FORMAT(1X,'ENTER STOP FREQUENCY, IN MHZ,F6.0')
   70 FORMAT(1X,'ENTER FREQUENCY INCREMENT, IN MHZ, F7.3')
   71 FORMAT(1X,'ENTER FREQUENCY TOLERANCE, IN MHZ, F7.3')
   72 FORMAT(1X,'ENTER HP 8690 FREQ. RANGE, IN GHZ, F7.3')
C  73 FORMAT(1X,'NOMINAL FRQUENCY=',F7.0,' MHZ',5X,'WAVELENGTH=',F7.3,
C    1' CENTIMETERS')
C  74 FORMAT(5X,'XP1=',F8.3)
C  75 FORMAT(1H1)
   76 FORMAT(2F10.3)
   77 FORMAT(1X,'ENTER TAPE NUMBER, I3')
   78 FORMAT(1X,'ENTER FILE NUMBER, I3')
```

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```
   79 FORMAT(I3)
   80 FORMAT(1X,'ENTER NUMBER OF FILES TO SKIP, I3')
   81 FORMAT(2I3,F10.3)
  101 FORMAT('5T@KMOH')
  102 FORMAT(A2,1X,E11.0)
      STOP
      END
$LAB= STEP
$DBUG
$TITL= +++++ SUBROUTINE STEP +++++    SEPTEMBER 14, 1976
      SUBROUTINE STEP(NADD,NSTEP,NWAIT)
      IF(NSTEP.EQ.0) RETURN
      DO 1 IS=1,NSTEP
      TEN=10.
      CALL AOUT(1,NADD,TEN,K)
      IF (K.NE.1) GO TO 4
      CALL WAIT(1,1,MERR)
      IF(MERR.NE.1) PAUSE 01111
      ZERO=0.
      CALL AOUT(1,NADD,ZERO,K)
      IF(K.NE.1) GO TO 4
      CALL WAIT(NWAIT,1,MERR)
      IF(MERR.NE.1) PAUSE 01111
    1 CONTINUE
      RETURN
    4 WRITE(4,51)
   51 FORMAT(1X,'SUBROUTINE ++ STEP ++ ERROR RETURN')
      PAUSE 02222
      RETURN
      END
ESTA LONGIT
PRIO 9
OPTI 0010 1001 1001 0000
ASSI 1,10,2,2,3,3F,4,55,5,85,6,62,7,0,A,83
GET 200
LOAD
LINK 506
EDIT 506
MAP 62
TASK 07
END
```

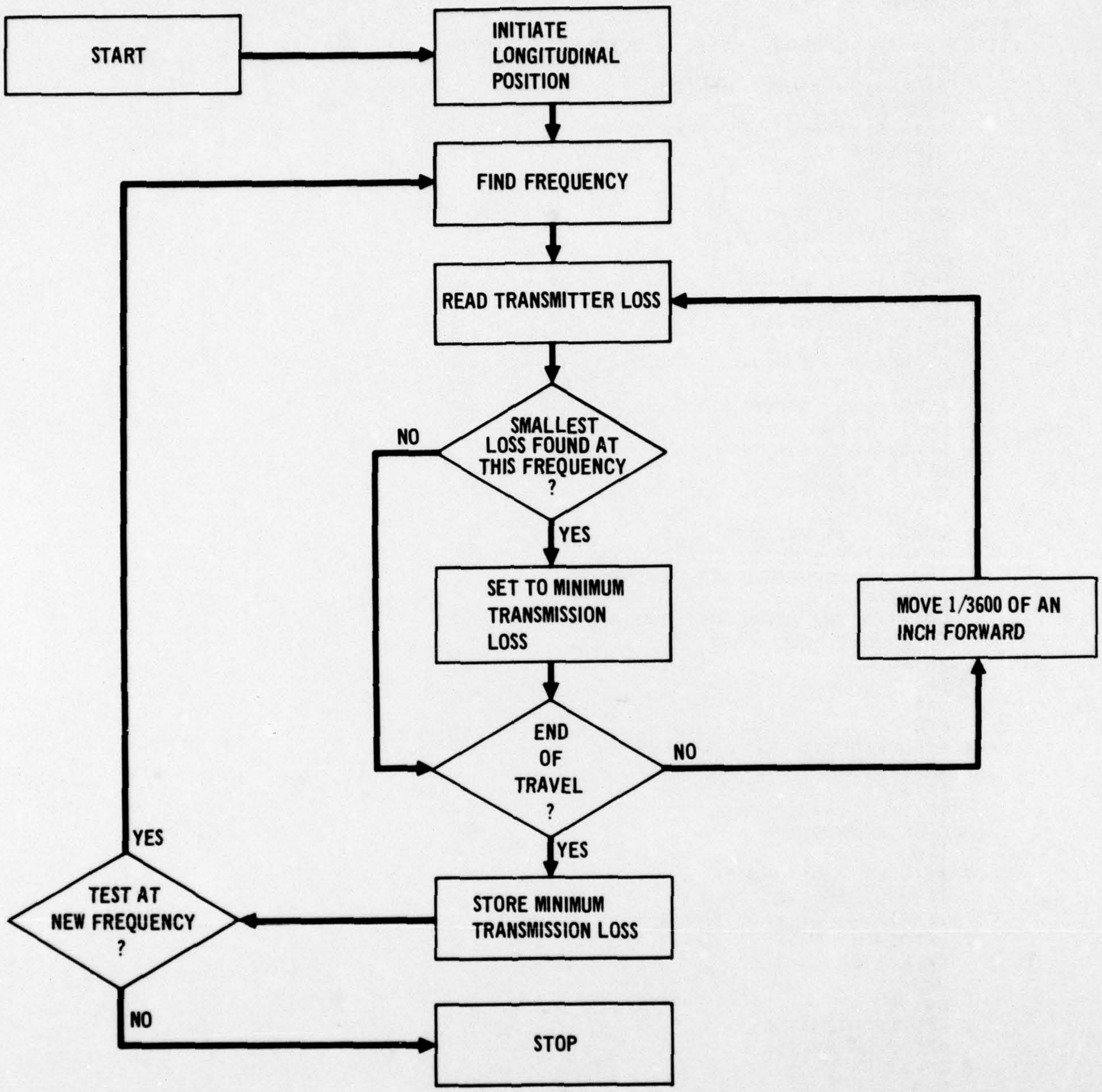

FIGURE D-4 FLOW CHART OF 'LONGON' – LONGITUDINAL TRANSLATION ONLY COMPUTER PROGRAM

```
$LAB= LONGON
$DBUG
$TITL= +++++  LONGON  +++++   OCTOBER 5, 1976
      REAL LFL
      DIMENSION JIN(2),AIN(2)
      INTEGER*2 SYM
      DATA CL/'?+%0'/,CT/'?+E '/
      JIN(1)=5
      JIN(2)=6
      WRITE(1,53)
      READ(1,54) NSKIP
      CALL FRFM(5,NSKIP)
      WRITE(1,55)
      READ(1,54) NTAPE
      WRITE(1,56)
      READ(1,54) NFILE
      WRITE(1,57)
      READ(1,58) STARTF
      WRITE(1,59)
      READ(1,58) STOPF
      WRITE(1,60)
      READ(1,61) FINCRE
      WRITE(1,62)
      READ(1,61) FTOL
      WRITE(1,63)
      READ(1,61) RANGEF
      IF(FINCRE.EQ.0.0) FINCRE=1.0
      IND=1+(STOPF-STARTF)/FINCRE
      FVOLT=0.0
      WRITE(5,64) NTAPE,NFILE,STARTF
      DO 11 L=1,IND
      X=-1000.
      I=0
      J=0
      K=0
    4 CALL AINHL(2,JIN,AIN,KERR)
      IF(KERR.NE.1) PAUSE 506
      I=I+1
      IF(I.LT.10) GO TO 1
      CALL STEP(9,1,0)
      I=0
    1 IF(J.LT.205) J=J+1
      IF(J.LT.200) GO TO 2
      IF(AIN(2).GT.1.0) PAUSE 1
    2 IF(AIN(1).GT.1.0) GO TO 3
      CALL STEP(12,1,3)
      J=J+1
      GO TO 4
    3 HFL=STARTF+FTOL
      LFL=STARTF-FTOL
    8 OVOLT=FVOLT
      M=0
      CALL AOUT(1,8,OVOLT,KERR)
      IF(KERR.NE.1) PAUSE 7777
      CALL WAIT(50,1,MERR)
      IF(MERR.NE.1) PAUSE 1111
      WRITE(3) CL
      WRITE(3,101,ERR=3,END=3)
      WRITE(3) CT
      READ(3,102,ERR=3,END=3) SYM,VALUE
      FMETER=VALUE/1000000.
      IF(FMETER.GT.HFL) GO TO 6
      IF(FMETER.LT.LFL) GO TO 7
```

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```
      GO TO 5
    6 FVOLT=FVOLT-.004
      GO TO 3
    7 FVOLT=FVOLT+.004
      GO TO 3
    5 CALL AINHL(1,7,P,KERR)
      IF(KERR.NE.1) PAUSE 7
      P=(P-1.5)/.05
      IF(P.GT.X) X=P
      CALL STEP(11,1,0)
      CALL STEP(9,1,1)
      CALL STEP(10,1,0)
      CALL AINHL(2,JIN,AIN,KERR)
      IF(KERR.NE.1) PAUSE 506
      IF(K.LT.205) K=K+1
      IF(K.LT.200) GO TO 9
      IF(AIN(1).GT.1.0) PAUSE 1005
    9 IF(AIN(2).GT.1.0) GO TO 10
      M=M+1
      IF(M.GT.200) GO TO 8
      GO TO 5
   10 WRITE(2,51) FMETER,X
      WRITE(5,52) FMETER,X
      FVOLT=FVOLT+(FINCRE*17.5)/(RANGEF*1000.)
   11 STARTF=STARTF+FINCRE
      ENDFILE 5
   51 FORMAT(1X,'FREQUENCY=',F7.0,' MHZ',5X,'XP=',F8.3)
   52 FORMAT(2F10.3)
   53 FORMAT(1X,'ENTER NO. OF FILES TO SKIP, I3')
   54 FORMAT(I3)
   55 FORMAT(1X,'ENTER TAPE NO., I3')
   56 FORMAT(1X,'ENTER FILE NO., I3')
   57 FORMAT(1X,'ENTER STARTF,IN MHZ, F6.0')
   58 FORMAT(F6.0)
   59 FORMAT(1X,'ENTER STOPF, IN MHZ, F6.0')
   60 FORMAT(1X,'ENTER FINCRE, IN MHZ, F7.3')
   61 FORMAT(F7.3)
   62 FORMAT(1X,'ENTER FTOL, IN MHZ, F7.3')
   63 FORMAT(1X,'ENTER HP8690 FREQ. RANGE, IN GHZ, F7.3')
   64 FORMAT(2I3,F10.3)
  101 FORMAT('ST@KMOH')
  102 FORMAT(A2,1X,E11.0)
      STOP
      END
$LAB= STEP
$DBUG
$TITL= +++++ SUBROUTINE STEP +++++   SEPTEMBER 14, 1976
      SUBROUTINE STEP(NADD,NSTEP,NWAIT)
      IF(NSTEP.EQ.0) RETURN
      DO 1 IS=1,NSTEP
      TEN=10.
      CALL AOUT(1,NADD,TEN,K)
      IF (K.NE.1) GO TO 4
      CALL WAIT(1,1,MERR)
      IF(MERR.NE.1) PAUSE 01111
      ZERO=0.
      CALL AOUT(1,NADD,ZERO,K)
      IF(K.NE.1) GO TO 4
      CALL WAIT(NWAIT,1,MERR)
      IF(MERR.NE.1) PAUSE 01111
    1 CONTINUE
      RETURN
    4 WRITE(4,51)
```

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```
   51 FORMAT(1X,'SUBROUTINE ++ STEP ++ ERROR RETURN')
      PAUSE 02222
      RETURN
      END
ESTA LONGON
PRIO D
OPTI 0010 1001 1001 0000
ASSI 1,10,2,2,3,3F,5,85,A,83
GET 200
LOAD
LINK 206
EDIT 506
MAP 62
TASK E06
END
```

The following two programs, **TPLOT2** and RPLOT2, plot data from the mag tapes generated from the data-gathering programs. TPLOT2 plots the transmission loss, and RPLOT plots reflection coefficients.

```
$LAB= TPLOT2
$DBUG
$TITL= +++++  TPLOT2  +++++      OCTOBER 6, 1976
       DIMENSION D1(614),X(201),Y(201),Z(201),NSYM(6)
      1,MSYM(6)
       EQUIVALENCE (D1(613),NTAPE),(D1(614),NFILE)
       DATA SAME/9999./,(NSYM(I),I=1,6)/42,30,28,31,33,35/
       DATA (MSYM(I),I=1,6)/10752,7680,7168,7936,8448,8960/
       CALL ZERO(X,201,1,1)
       CALL ZERO(Y,201,1,1)
       CALL ZERO(Z,201,1,1)
       YPOS=6.0
C      WRITE(1,54)
C      READ(1,55) NPEAK
C      WRITE(1,56)
C      READ(1,55) NAVE
C      WRITE(1,57)
C      READ(1,55) NPLOT
C      WRITE(1,60)
C      READ(1,61) FSTART
       CALL MODE(2,9.5,SAME,SAME)
       CALL MODE(5,SAME,SAME,441.)
       CALL MODE(7,9.0,7.0,SAME)
       CALL MODE(9,-35.,5.,SAME)
       J=1
C      DO 3 J=1,NPLOT
       WRITE(1,58)
       READ(1,52) NSKIP
       CALL FRFM(5,NSKIP)
       DO 2 I=1,201
     5 READ (5) D1
       IF(I.EQ.1) FSTART=INT(D1(601)+.5)/1000.
C    6 Y(I)=D1(608)
       Z(I)=D1(612)
     2 X(I)=D1(601)/1000.
C      IF(NAVE.NE.1) GO TO 1
C      CALL NOTE(X,Y,NSYM(J),-201)
C    1 IF(NPEAK.NE.1) GO TO 4
       CALL MODE(8,FSTART,.025,SAME)
       CALL NOTE(X,Z,NSYM(J),-201)
     4 CALL NOTE(8.1,YPOS,'TAPE ',5)
       CALL NOTE(8.6,YPOS,NTAPE,0)
.      CALL DRAW(X1,Y1,-1,0)
       CALL NOTE(X1,YPOS,'-',1)
       CALL DRAW(X1,Y1,-1,0)
       CALL NOTE(X1,YPOS,NFILE,0)
C      ZPOS=YPOS+.05
       CALL NOTE(9.25,YPOS,MSYM(J),1)
     3 YPOS=YPOS-.25
C      IF(NPEAK.NE.1) GO TO 7
       CALL NOTE(8.1,6.75,'PEAK POWER',10)
C    7 IF(NAVE.NE.1) GO TO 8
C      CALL NOTE(8.1,6.5,'AVERAGE POWER',13)
     8 CALL.FORM(8,1.,7,1.)
       CALL AXES(15.3,'FREQUENCY (GHZ)',22.0,'TRANSMISSION LOSS (DB)')
       CALL DRAW(0.,0.,1,9000)
       CALL DRAW(0,0,0,9999)
    52 FORMAT(I3)
    54 FORMAT(1X,'IF YOU WISH PEAK POWER, TYPE 1')
    55 FORMAT(I1)
    56 FORMAT(1X,'IF YOU WISH AVERAGE POWER, TYPE 1')
    57 FORMAT(1X,'ENTER NO. OF PLOTS PER PAGE IN THE FORM X. MAX=6')
    58 FORMAT(1X,'ENTER NO. OF FILES TO SKIP, IN THE FORM XXX')
```

```
   59 FORMAT(1X,'IF THIS IS DIMENSIONED 612, TYPE 1')
   60 FORMAT(1X,'ENTER START FREQUENCY, IN GHZ, E7.3')
   61 FORMAT(F7.3)
      STOP
      END
ESTA TPLOT2
PRIO 9
OPTI 0010 1001 1001 0000
ASSI 1,10,2,62,5,85,6,2,8,1106
GET 200
LOAD
LINK 1406
EDIT 1406
EDIT 506
MAP 62
TASK E06
END
```

```
$LAB= RPLOT2
$DBUG
$TITL= +++++  RPLOT2  +++++        JULY 27,1976
      DIMENSION D1(614),C(10),X(201),Y(201)
      EQUIVALENCE (D1(613),NTAPE),(D1(614),NFILE)
      DATA SAME/9999./
      YPOS=6.0
      CALL ZERO(X,201,1,1)
      CALL ZERO(Y,201,1,1)
      CALL MODE(2,9.5,SAME,SAME)
      CALL MODE(5,SAME,SAME,441.)
      CALL MODE(7,9.0,5.5,SAME)
      CALL MODE(9,0.0,0.2,SAME)
      CALL MODE(10,-1.,SAME,SAME)
C     DO 9 K3=1,201,100
C     K2=K3+100
      WRITE(1,50)
      READ(1,51) NSKIP
      CALL FRFM(5,NSKIP)
      DO 6 K=1,201
      READ(5,END=8) D1
      IF(K.EQ.1) FSTART=INT(D1(601)+.5)/1000.
      IF(K.EQ.1) WRITE(2,57) NTAPE,NFILE
      X(K)=(D1(601)-.0)/1000.
      IE=1
      PEAK=-1000.
      DO 2 I=1,200
      IF(D1(I+400).LT.PEAK) GO TO 2
      IF(D1(I+400).NE.PEAK) GO TO 3
      IE=IE+1
      IF (IE.GT.10) GO TO 2
      GO TO 4
    3 PEAK=D1(I+400)
      IE=1
      DO 1 M=1,10
    1 C(M)=2.
    4 A=D1(I)
      B=D1(I+200)
      C(IE)=SQRT(A*A+B*B)
    2 CONTINUE
      DO 5 J=1,9
      JJ=J+1
      DO 5 I=JJ,10
      A=C(J)
      IF(C(I).GE.A) GO TO 5
      C(J)=C(I)
      C(I)=A
    5 CONTINUE
      IF(C(2).EQ.2.) GO TO 6
      WRITE(2,53) (C(IE),IE=1,10),X(K)
    6 Y(K)=C(1)
    9 CONTINUE
    8 WRITE(2,56)
      CALL MODE(8,FSTART,.025,SAME)
      CALL DRAW(X,Y,201,441)
      CALL NOTE(8.1,YPOS,'TAPE ',5)
      CALL NOTE(8.6,YPOS,NTAPE,0)
      CALL DRAW(X1,Y1,-1,0)
      CALL NOTE(X1,YPOS,'-',1)
      CALL DRAW(X1,Y1,-1,0)
      CALL NOTE(X1,YPOS,NFILE,0)
      CALL FORM(1,8.,1,5.)
      CALL MODE(10,4369.,SAME,SAME)
```

```
      CALL FORM(8,1.,5,1.)
      CALL MODE(10,0.,SAME,SAME)
      CALL AXES(15.3,'FREQUENCY (GHZ)',22.2,'REFLECTION COEFFICIENT')
      CALL DRAW(0.,0.,1,9000)
      CALL DRAW(0,0,0,9999)
   50 FORMAT(1X,'ENTER NUMBER OF FILES TO SKIP, I3')
   51 FORMAT(I3)
   53 FORMAT(10F6.2,F7.3)
   54 FORMAT(1X,'GREATER THAN 10')
   55 FORMAT(I1)
   56 FORMAT(1H1)
   57 FORMAT(1X,'TAPE=',I3,5X,'FILE=',I3,//)
   61 FORMAT(F7.3)
      CALL FRFM(5,1)
      STOP
      END
ESTA RPLOT2
PRIO 9
OPTI 0010 1001 1001 0000
ASSI 1,10,2,62,3,0,5,85,6,2,8,11C6
GET 200
LOAD
LINK 14C6
EDIT 14C6
EDIT 5C6
MAP 62
TASK 207
END
```

9 Final rept. Jun 76 - Mar 77,

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18 NSWC DL

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Improvements to the MIL-STD-1377(Navy) technique are described. Eight field tuner designs were tested and evaluated and a matched long-wire antenna design is described. Chamber performance, as measured by reduced peak-to-peak variations in transmission loss, was greatly improved at the low end of the frequency band (1-2 GHz). The report recommends that MIL-STD-1377 (Navy) be amended to include the improved tuning schemes and antennas.

A sub-task showed that bare wires pick up RF power according to an inverse square of frequency law and that a halfwave dipole approximation is quite good from 100 MHz to 2 GHz.

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